COGNITIVE PROCESSING IN COMPLEX SITUATIONS : THE DYNAMICS OF INFORMATION FLOW

Robert Bruce Lee

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews

1974

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COGNITIVE PROCESSING IN COMPLEX SITUATIONS : THE DYNAMICS OF INFORMATION FLOW

by

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Doctor of Philosophy

University of St. Andrews

August 1974

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Certificate

I hereby certify that Mr Robert Bruce Lee has completed nine terms of research work under my supervision, has fulfilled the conditions of the Resolution of the University Court, 1967, No. 1, and that he is qualified to submit the accompanying thesis in application for the Degree of Doctor of Philosophy.

Research Supervisor

2 August 1974

DECLARATION

I hereby declare that this thesis has been composed by myself, that the work of which it is a record has been done by myself and that it has not been accepted in any previous application for a higher degree in the University of St. Andrews or elsewhere.

Signed:

Robert Bruce Lee

14 August, 1974.

ABSTRACT

Cognitive processing performance in complex situations - the dynamics of information flow.

Ph.D. thesis by Robert B. Lee,

Department of Psychology, University of St. Andrews.

The thesis describes and develops a new theoretical approach to the study of human cognitive processing performance in complex situations. This approach utilises and integrates existing theoretical and empirical data from a number of traditionally separate areas of information processing psychology, such as cognition, perception, memory, imagery, skill and vigilance.

Contemporary cognitive psychology considers perception, memory and imagery as functionally inter-related and inter-dependent processes characterised by active, constructive, conscious information processing. In the present thesis the implications of this view are extended, in that this processing is considered to occupy the cognitive processing capacity of the subject in qualitatively the same way as does normal decision-making, problem-solving, or conscious internalised thought processing of any kind. Existing research evidence accumulated over the past 20 years suggests that this conscious information processing capacity is limited.

In dual-task situations inter-task interference resulting from attention alternating between the information processing requirements of the two tasks, has been demonstrated in numerous experiments. If the above cognitive view of perception, memory and imagery is correct, such inter-task interference should take place between 'externalised' and 'internalised' tasks, - i.e. thought processes should interfere with visual perception. There exists

some experimental evidence that this is the case in certain situations. However, unlike the inter-task interference observed in typical dual-task situations, our ongoing conscious stream of perceptual awareness does not appear to be continually intermittently interrupted as information processing referent to some other cognitive task 'captures' the single channel.

There is evidence from one area of research that memory information concerning expected, over-learned familiar visual patterns may be incorporated into the perception of such patterns. Conversely, the recent increase in research investigation into the phenomena of mental imagery has demonstrated that real sensory information may be incorporated into internally synthesised images. Perceptual information emanating from real sensory information input and perceptual information emanating from memory, in the form of images, may be phenomenally indistinguishable at the level of conscious perceptual experience.

The present thesis re-appraises the possible function of the mechanisms of the imagery system. It is suggested that the role of imagery in human performance in familiar perceptual environments is to reduce the cognitive processing requirements referent to the analysis of real sensory information from these environments, thereby making available additional capacity for thinking, while moving about in these environments. The imagery system may be utilised in these situations to augment or enhance partially processed real sensory information. In this way, conscious perceptual experience is not interrupted, but the total amount of information forming this experience may consist, at any instant, of a composite of information from memory and from the real environment. The relative amounts of real and memory-derived information may vary continuously according to such factors as the subjective focussing of attention of the perceiver, or the degree of over-learning or expectation of the patterns involved. A number of eminent investigators in somewhat different areas of psychology (e.g. Bartlett, Welford, Bruner, Piaget, Neisser) have put forward the idea that much of what is perceived is, in fact, inferred. It is suggested that there exists a system by means of which this may occur, and this is the imagery system.

The theoretical approach of the thesis stresses and accepts the functional inter-relationship and inter-dependence of the various higher mental processes, and is primarily concerned with the sustained dynamic performance properties of the total system.

The nature of the research emphasis and direction of the thesis originates from the author's direct concern with applied problems resulting from the increasing cognitive load imposed upon human operators in present complex man-machine systems, such as jet aircraft, for example. Performance failure of the human operator in these systems often has very serious consequences. There is a critical lack of knowledge regarding the fundamental nature and limitations of human information processing in such situations. The basic motivation behind the work reported in the thesis was that, in order to study meaningfully the relevant aspects of the applied situation, further pure research, both theoretical and empirical, had to be undertaken to clarify particular issues. Much applied research has been restricted to a particular kind of psychological approach. It is felt that the scope of this approach may be too restricted. Many other areas of psychological research have been ignored by most applied psychologists (e.g. imagery), yet the cognisance of research information from these areas may well offer a fresh approach to applied problems and perhaps offer some new solutions, or, at least, allow the asking of new questions.

An experiment is described which utilises the known indicative relationship of eye movement activity to the amount of processing of visual sensory information. This experiment confirmed the theoretical prediction that such processing will be considerably reduced when subjects are engaged in thinking, and will be increased when they are not performing any stimulus-independent cognitive activity.

As a result of the factors outlined in the foregoing discussion, some of the experiments reported in the thesis are concerned with the recognition of expected, over-learned, complex visual patterns under conditions in which only partial attention may be dedicated to this task. The remaining processing capacity is utilised in the simultaneous performance of an internalised cognitive task, which involves no associated visual sensory input. The complex visual patterns used in these experiments are not the usual dot matrices or line drawings, but photographs of real, familiar perceptual environments. The experiments make use of the considerable power of picture memory, which enables pictures to be rapidly and effectively over-learned. The photographs are divided into heterogeneous categories, each category being represented by a set of homogeneous pictures. Subjects' memory performance was evaluated in terms of two error indices, one referent to the picture category, and one to the specific picture. Recognition was tested by exposing the pictures for short intervals while subjects were attempting to solve difficult mental problems. Some new and powerful effects have been demonstrated and replicated in these experiments which confirm, at a highly significant level, the particular empirical predictions derived from the theory. There was <u>no</u> performance difference in relation to the identification of the heterogeneous picture categories between the subjects tested in the above situation, and a control group who did not have to perform the mental task during recognition. However, there was a highly significant difference between the groups in relation to the identification of specific pictures.

Individual performance characteristics and error patterns in the experiments were related to a questionnaire index of vividness of visual imagery. On the basis of the theoretical ideas developed, it was predicted that in situations where all conscious attention is dedicated to performance of the memory task, 'high' imagers would perform <u>better</u> than 'low' imagers. In contrast, in the divided attention case, the prediction was that 'high' imagers would perform <u>worse</u> than 'low' imagers. Both these separate theoretical predictions were empirically supported.

A new conceptual approach to vigilance-type situations is suggested by the theory developed in the thesis. A task was devised in which the signals to be detected were clearly visible, but embedded at random in complex visual patterns (photographs). These patterns were presented on a television screen at regular intervals, over 600 times to subjects during a single testing session. At each of these presentations subjects had to respond with respect to the identification of the picture shown, and to the presence or absence of a signal within it. From the theory it was predicted that where the complex pattern remained the same throughout the testing session, signal detection performance would show a typical vigilance decrement. However, when the set of possible pictures in which the signal may or may not be embedded is vastly increased, and the subject has to respond at each event in the manner described, it was predicted that signal detection performance would be significantly improved in relation to the single picture condition. These predictions were empirically confirmed at a highly significant level. (On the basis of visual signal - to - noise ratios only, a signal detection analysis of the experimental situation would predict a result opposite to that actually obtained in the experiment).

A computer simulation program based on fundamental theoretical ideas outlined in the thesis was developed. The program was used to simulate the vigilance experiment reported in the dissertation. The purpose and implications of the use of this technique as an applied research tool are discussed.

The final chapter discusses the results achieved, and outlines the proposed application of the theoretical ideas, and empirical results of the research to the cognitive load problems of human operators in real man-machine systems, in particular aircrew flying advanced jet aircraft.

ACKNOWLEDGEMENTS

I express sincerest gratitude to my supervisor, Professor M.A. Jeeves, for the contribution he has made towards the research reported in this thesis. His constant encouragement and advice, which was both constructive and critical, were of great value both in guiding and maintaining the research on the path towards its intended goals.

I thank Mr. Brian Sibbald for his considerable efforts in translating my ideas into practical computer programs. I thank also Miss Anne Parsons for her assistance with the recording of video tapes. I thank Mr. Tony Toon and Mr. Gordon Patterson for their indispensable and willing help with the design, construction and development of the experimental apparatus.

I am grateful to the staff of the University Photographic Services Unit for the taking and printing of photographs, both for the experiments and for the thesis. I thank Mrs. W. Mathewson, who typed the thesis.

I offer particular thanks to all those who participated as subjects in the research, both in the pilot studies and in the final experiments. These were often difficult, frustrating and time-consuming. However, the co-operation, interest and enthusiasm shown by all subjects was uniformly of a very high order, and was greatly appreciated.

Finally, I wish to acknowledge with special gratitude, the contribution to the study of my wife Diane, whose continuing encouragement and understanding has enabled this thesis to be written.

CONTENTS

CHAPTER I

Background, Introduction, and development of the theoretical approach.

1.1 The late Sir Frederick Bartlett stated as long ago as 1932 that psychologists have persistently treated "every mental process as presenting problems the answer to which can be found without searching beyond the limits of the specific process itself." (Bartlett, 1932, p.187). He pointed out that "it is impossible to understand any high level mental process if it is simply studied by and for itself" (ibid., p.186). It would seem plausible to argue that the reason for the continued (and continuing) persistence of "faculty psychology" is directly related to the unwillingness or inability of many investigators to come to terms with the manifold complexities of these interacting processes. Reitman (1970) has strongly argued that, if it is acknowledged that all behaviour is a function of a wholly integrated system, the various processes (e.g. perception, memory etc.) may be too interrelated to separate, and the investigation of such processes in isolation may involve no more than arbitrary and artificial problems.

The rapid and continuing technological advances of the last three decades have provided psychologists with powerful new tools with which to study the complexities of human behaviour. Fundamentally, many conceptual areas of research interest have not changed, however much the relevant descriptive terminology may have altered. In spite of this basic adherence to the investigation of the same underlying phenomena, it has become to some extent possible, by means of new analogies and languages associated with technological change, "to cope now with problems which psychology had put aside as too difficult a decade and more ago." (Broadbent, 1971, p.2). That psychologists can now cope with such problems illustrates clearly the way in which increases in knowledge about a phenomenon "are inextricably a function of technical and methodological advances, as well as theoretical advances." (Yates, 1972, p.2).

Primarily, the greatest significance of these changes is that experimental psychologists can now acknowledge and investigate complexity. The most important single aspect of this new technology for the study of human behaviour has been the advent of the readily available general purpose digital computer, and the continuing research and development leading to its increasing adaptability and refinement. Theories and models of complex behaviour patterns which are not necessarily simplistic can be developed and tested, often by computer simulation techniques. This has led to the claims of psychologists such as Apter, for example, that the computer modelling of psychological processes may eventually provide the most important contribution to man's knowledge of himself. (Apter, 1970, p.1). In addition to simulation of human behaviour, computers may also be used to generate complex visual displays for use in psychological experiments.

The specialised scientific and technical knowledge and expertise necessary to the realistic investigation of complex phenomena increasingly involves several of the traditional academic disciplines (Uhr, 1966). Investigators in different disciplines have not taken cognisance of the work of others in other disciplines, and are often totally unaware of it.

Fortunately, however, many psychologists are recognising this problem, and interdisciplinary research programs are now common.

To keep the evaluation of these advances in some perspective, it should be pointed out that the relative ease with which the predictions of complex theories can be calculated on a computer has been called "a retrograde step" by Broadbent (1971, p.6). He argues that psychology has, in general, come to concentrate on specialised theorising of particular cognitive and behavioural phenomena, in contrast to the all-embracing theoretical approach of Hull (1952), for example. Particular theories, however, are now able to become so elaborate that they "outrun" the possibility of unambiguous experimental validation. (Uhr, 1966, p.6).

A further valid criticism of the current state of much psychological theorising is that the formulation of theories may tend to become governed by the technological hardware they employ in their modelling. Some current extremes in the fashionable human brain - computer comparison which overlook the obvious differences between them are cases in point (Apter, 1970, p.19). The once great enthusiasm for "machines which think like men" dissipated as the consequences of the differences between biological systems and digital computers became clear. (von Neumann, 1958).

Although such criticisms as those described above may well be warranted in some instances, they do not discredit the serious and considered analytical approach which utilises these new facilities.

1.2 A new conceptual approach to psychological research, which, by its terminology and analogies clearly shows the direct influence of other disciplines - notably mathematics and communications engineering, is generally termed the "Information Processing approach." (e.g. Broadbent, 1971; Reitman, 1965). This approach stresses the value of "analysing human function in terms of the flow of information within the organism." (Broadbent, 1971, p.7).

The basic notions of this approach can be traced back to the publication of two papers by Craik (1947, 1948) and the appearance of three important books at the end of the 1940's. These were "Cybernetics" by Weiner (1948); "The Mathematical Theory of Communication" by Shannon and Weaver (1949); and "Statistical Decision Functions" by Wald (1950). Weiner's book utilised mathematics to propose ideas for regarding man as a self-regulating mechanism and presented the basic conceptsof Information Theory. The notions of Information Theory were expanded and put forward as a set of theorems in Shannon's and Weaver's work. Wald's book laid the foundations for the application of statistical decision theory to human performance.

The growth of research interest in what has been termed Behavioural Cybernetics (Smith, 1966), where the basic assumption is that the organisation of motor performance and the pattern of learning are connected with the characteristics of closed-loop feedback control which an individual maintains over his own behaviour, and the rapid growth of Cognitive Psychology (Bower, 1970) can be attributed largely to the information processing approach to psychological problems.

1.3 Possibly the most potentially important and one of the most recent areas of research generated by information-processing psychology is that of pattern recognition. Uhr (1966, p.1) notes that philosophers and psychologists have been "strangely silent" about patterns, (although Bartlett was using the concept of pattern in the contemporary sense many decades ago, and the Gestalt psychologists were very much concerned with the specific area of perception of geometric patterns). However, states Uhr, an increasing number of investigators are coming to recognise that many of the central cognitive characteristics of the human organism - intelligence, thinking, remembering, perceiving, learning - are characteristics that involve patterns.

In perception, for example, one of the critical problems has been to explain "why things look the way they do." (Vickers, 1971, p.1). Gestalt theory has been largely concerned with the ability of the human perceptual system to organise information from unfamiliar, ambiguous or meaningless stimulus arrays "into perceptions that amount to clear and simple descriptions of what we see." (ibid.).

Virtually since the adoption of information concepts by psychologists (see Attneave, 1959) attempts have been made to relate them to problems of pattern perception, but with limited success (Garner, 1962). Garner states that the attraction of the concepts of information theory in the study of patterns is that they are potentially capable of dealing with organisation and structure in a quantitative manner - "the very things which have seemed to be the essence of the nature of pattern perception" (ibid., p.175). However, as Garner points out, the application of these concepts has not met with great success to date. There has been no satisfactory evolution of a psychophysics of form. In particular, the informational quantification of the intuitively appealing pattern perception notions of Gestalt psychology, such as "goodness of figure", "configuration", and so on, has proven extremely difficult. However, in recent years, claims Vickers (1971), the interpretation, interrelations and applications of some of these Gestalt principles have become sufficiently clarified and precise to enable them to be evaluated experimentally.

In the related field of intelligence, after the pioneering computer simulation of human problem solving by Newell, Shaw and Simon (1958 onwards - reviewed in Newell & Simon, 1972), a very large literature developed. Hunt (1971) refers to "over a thousand papers" on the computer simulation of aspects of human intelligence. Importantly, he also notes that, although there have been numerous reviews and collections of papers, with the exception of Reitman (1965) there has been little effort directed towards theoretical integration. In a major attempt to achieve such a state, Hunt (1971) presents a model of man's cognitive processes based on an analogy between a human being and a computing <u>system</u>; i.e. the analogy is to the <u>organisation</u> of the computing system and not to its components. Hunt puts forward his "Distributed Memory" model as a framework to guide research, but admits, in doing so, that his theoretical basis is incomplete. He acknowledges also that it would be difficult and potentially vastly expensive to test.

1.4 The investigation of the nature and properties of human information processing has become an increasingly important applied problem. Man has become a component of complex man-machine systems, such as modern jet aircraft, for example. The continued retention of the control functions of the human operator in such systems is almost entirely attributable to man's cognitive flexibility and decision-making capabilities (Fogel, (1964) - in Singleton, Easterby and Whitfield (1967), p.xii.). The primary load modern systems place upon the human operator is a mental load. The human operator's once previously essential function as a source of mechanical power is now largely redundant (Chapanis, 1965, p.11).

The relative lack of knowledge concerning the basic information-processing properties, capabilities and limitations of the human operator in relation to other machine components of a system, and the consequent inability to make reliable predictions concerning operator performance constitutes the weakest link in the design of such systems. (de Sola Pool, 1964 - in Siegel and Wolf, 1969, p.vii). Because the consequences of the failure of these complex systems can be catastrophic, resulting in the loss of hundreds of human lives, it is obviously essential that the fundamental limiting characteristics of human information-processing performance be defined as far as possible. It is necessary to avoid, both at the design and operational level, instances of human operators being placed in systems in which they cannot either perform at their maximum efficiency when the system is fully serviceable, or compensate for potential failures of other components of the system - even though in the latter case they may function completely adequately when the system is fully serviceable.

There are a number of common characteristics in relation to the information-processing requirements of the human operator in a wide range of typical complex systems. This is so, even though the specific operator work environments may be quite different superficially. (e.g., an aircraft cockpit vs an electric power station control room). The primary shared characteristics of these situations are as follows :-

1) The human operator must continuously divide his visual attention between a number of different external (i.e. to the operator) sources of information input in the integrated

performance of a number of separate sub-tasks. His perception of this visual information must be accurate.

2) Coincident with the requirements of 1), there is also a considerable and continuously variable internalised cognitive load imposed on the operator by the necessity for correct recognition, analysis and integration of the visual sensory information patterns according to predetermined criteria and procedures contained in memory.

3) The correct visual pattern and cognitive processing strategies in relation to 2) which are appropriate to the possible set of definitive internal states and global physical configurations of the particular system are thoroughly over learned by the qualified operator, i.e. they are able to be completely specified from memory information acquired during extensive training and practice.

In more general terms, the human operator is expecting the occurrence of sets of familiar, highly overlearned visual patterns according to the overall state of the system. For example, in the case of an aircraft, the pilot expects to see instrument patterns which indicate satisfactory states of internalised system components (e.g. the engines, hydraulic systems) together with instrument patterns indicating the satisfactory physical state of the aircraft (e.g. airspeed, rate of climb). The correct instrument pattern depends on the particular global state of the system (e.g. take-off, landing), and varies according to changes in that state. Thus, the instrument and control displays have different but consistent patterns appropriate to different global states.

4) For the entire period during which he is a component of the functioning system, the human operator must hold accurately in memory a large repertoire of specialised control procedures which he may be required to rapidly and accurately implement in order to compensate either for possible failures in other system components, or for unusual external physical forces acting on the whole system. The most appropriate of these procedures to implement is dependent on the operator's evaluation of the particular global state of the system at the time of the crisis situation.

Further, the most appropriate procedure to select and implement in an emergency situation may not be immediately obvious. In such situations a considerable additional cognitive loading relating specifically to the optimal selection of the most suitable compensatory procedure is imposed on the operator, while, at the same time, the requirement for accurate visual perception of the instrument and control displays is even more important than when the system is functioning normally.

1.5 The theoretical, experimental and simulation research to be reported in the present study is addressed primarily to the investigation of some of the fundamental aspects of human information-processing in complex situations characterised by the properties described in the previous section. A long term aim of the work is to utilise the theoretical and empirical findings in real applied man-machine situations.

The theory is concerned with the dynamics of the flow of information within the organism, and it involves a reappraisal of some of the traditional psychological concepts involved. The theory is derived from several diverse areas in information-processing psychology - areas which are still rapidly changing. As Reitman (1965) states, information processing theories "examine the representations and processes involved in cognitive activity. They emphasise the functional properties of thought and the things it achieves." (ibid., p.1).

The present work firstly develops a theoretical model emphasising particular functional characteristics of the cognitive system which is intended to provide an organising framework for systematic thinking about certain theoretical and applied psychological problems. Secondly, new experimental procedures which test the predictions of the theory will be described, and the results reported and interpreted. However, as Reitman observes, (ibid., p.38), in theories which attempt to deal with the complexity of human cognitive processes it is unwise to make prediction the "sole touchstone." No theory as yet has had much predictive significance in this area. Hence, part of the overall purpose of the work is that of exploratory information gathering. The evolution of the present conceptual approach will be illustrated in its description and, wherever possible, existing experimental and theoretical data from diverse areas of cognitive psychology, information theory, human performance, pattern recognition, perception, memory, etc... will be evaluated in terms of its degree of support for the present approach.

This overall approach is congruent with the "philosophy of information processing" outlined by Hunt (1971), which is epitomised by the consideration of perception and memory as constructive processes (Neisser, 1967) - i.e. "activity in view of ends" (Mackay, 1969). The present approach is also in accordance with Mackay's mentalistic philosophical position in that it considers that subjective conscious experience is a legitimate basis from which to derive and on which to test a psychological theory. The usefulness of such theories must ultimately be evaluated in these terms.

The following theoretical model deals with principles of organisation of the system, references being made to hypothesised system components without presenting detailed descriptions of the physiological mechanisms underlying their operation. (see also Hunt, 1971). Piaget (1969) has strongly justified such abstract theoretical models on the grounds that, if such models lead to a system of well formulated laws, they constitute the "best preparation for a complete physiology whose elaboration has scarcely begun." (ibid., p.xxiii).

Kaneff (1972) states that the usual approach of information processing psychologists to the complex problems of human behaviour has been to postulate block or flow diagrams in terms of selected functional processes, and then to investigate in detail only one, or very few, of these processes. However, like Reitman (1970), he argues that this method is subject to great difficulties stemming from the fact that perceptual and cognitive systems are integral entities with highly interactive and interdependent parts and "therefore need to be studied as such" (ibid., p.28). While still employing the useful conceptual utilisation of flow diagrams, the present approach attempts to relate to the <u>overall</u> performance characteristics of the total dynamic system in the particular type of situation described previously (p. 7).

1.6 Returning specifically to the field of pattern recognition, (or "pattern cognition" (Kaneff, 1972)), much of the research reported in the literature to date has involved attempts to construct theoretical or actual machines which recognise patterns that resemble those recognised by humans - for example, the recognition of letters and numerals, recognition of shapes etc.... The great proportion of the literature in this area is concerned with aspects of pattern recognition in the visual sense modality. Vickers (1972), Uhr (1966), Watanabe (1969) and Garner (1962) provide useful and comprehensive reviews of this work.

Information from the environment impinges directly upon human sensory receptors and is first transduced into an electrical signal. Hunt (1971) states that, when this has been done, it is found that the environment consists mainly of highly redundant information which, if responded to in detail, "would quickly swamp our minds" (ibid., p.60). The visual system alone is capable of transmitting information to the brain at the rate of 4.3×10^6 bits/second. In contrast, it has been estimated that silent reading, intuitively one of man's most rapid means of understanding the environment, proceeds at about 45 bits/second. If it is assumed that the reader comprehends and recalls every word read, one must still account for the fact that only one out of every 100,000 bits input to the brain remains there.

Data such as these well illustrate why one of the most important problems in the field of pattern recognition is the problem of feature extraction. Attneave (in Garner, 1962, p.200) thus claims that the "major function of the perceptual process ... is to describe or encode any stimulus in as economical form as possible and that, basically, the problem of describing a figure is determining the minimum number of parameters needed to specify the figure." Selfridge (1955) has <u>defined</u> pattern recognition as "the extraction of the significant features from a background of irrelevant detail." Numerous attempts have been made to model this process, (which is clearly a fundamental aspect of selective attention (e.g. Broadbent (1958, 1971)), as it relates to visual perception. Most of this literature has considered 'ad hoc' properties of 2-dimensional patterns, such as cusps, vees, straight lines, arcs, bays, etc... (Parker and Moore (1972)).

However, Parker and Moore (1972) have proposed a new fundamental approach to the derivation of features in a pattern. It is claimed that "a feature can be simply defined as a particular sort of non-random distribution of the points defining the pattern. Thus structure in the pattern is a non-random statistical distribution of some kind" (ibid., p.59). Parker and Moore consider some limited examples of both global and local analyses of shape, showing how features can be detected and extracted mathematically from patterns and how these features may then be enhanced in the patterns. Two global structure measures which can be used in the characterisation of simple shapes are defined, these characterisations being invariant to translations, rotations and dilations of the patterns. The precise details of the mathematical analyses involved are not of immediate concern to the present study. Those areas of Parker's and Moore's research which are of importance to this thesis are the functional aspects and the psychological implications of the processes described.

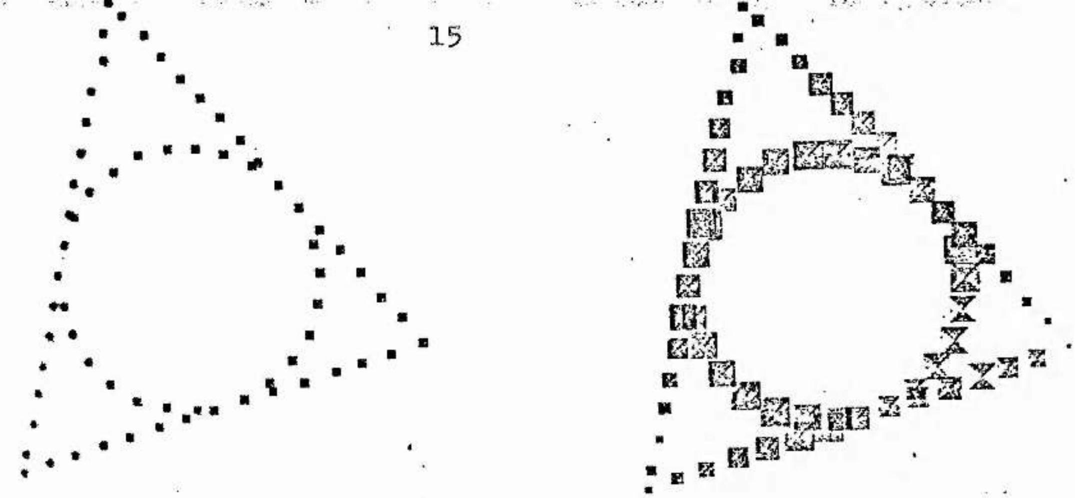
In particular, the notion that the analysis of a pattern may lead to the 'enhancement', or subjective perceptual exaggeration, of those points within the pattern which contribute most to its total overall structure is of much relevance to the psychology of human pattern recognition performance.

Three pictorial examples of the process are shown in Fig. 1.

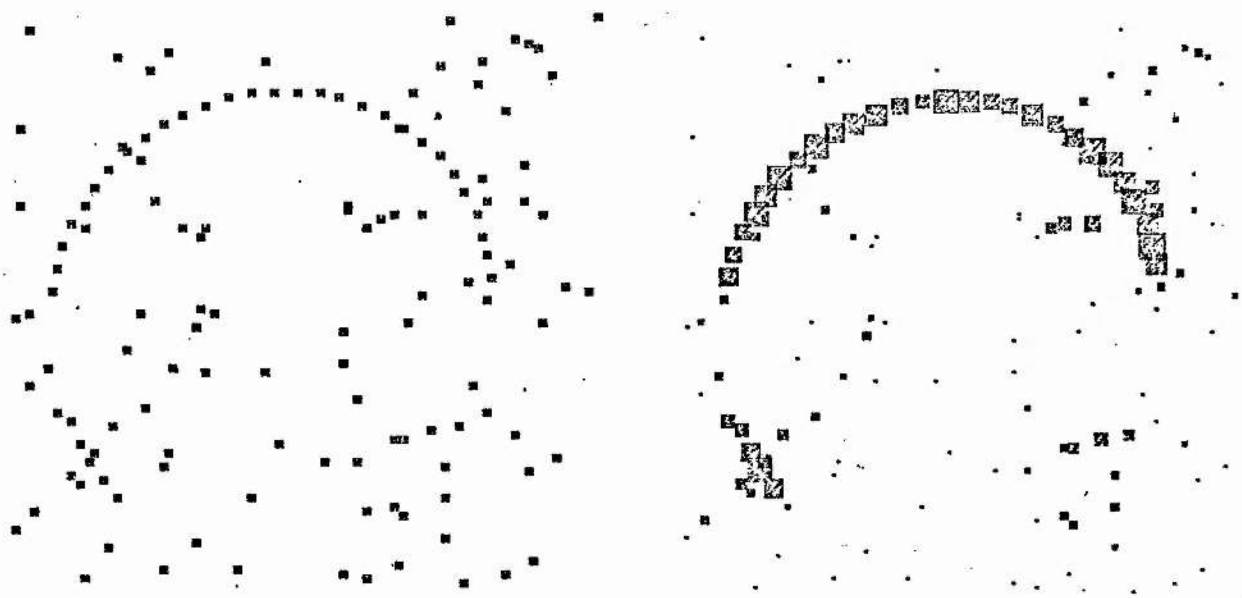
From this conceptual approach to the structural analysis of patterns, Moore and Seidl (1972) have further extended the possibilities in a paper entitled "A Gestalt Theory of Machine Perception". Once again, although primarily a mathematical model, the psychological implications are extremely important, especially as the research is claimed to be inspired by Gestalt principles. Wertheimer (1938) considered the perceptual process as the basic organisation of sensory data. This organisation was described in terms of a mapping from the unorganised sensory input of the geographical environment to a "configuration." The concept of "configuration" was, in effect, an abstract representation of the coding and organisation of the sensory information.

Moore and Seidl examine the nature of this Gestalt concept from a new mathematically based standpoint, and proceed to define two types of automaton, named a perception automaton and an association automaton. The function of the perceiving automaton is to organise the sensory data input into a configuration and to indicate what parts of this data contribute to that configuration, in the manner proposed by Parker and Moore.

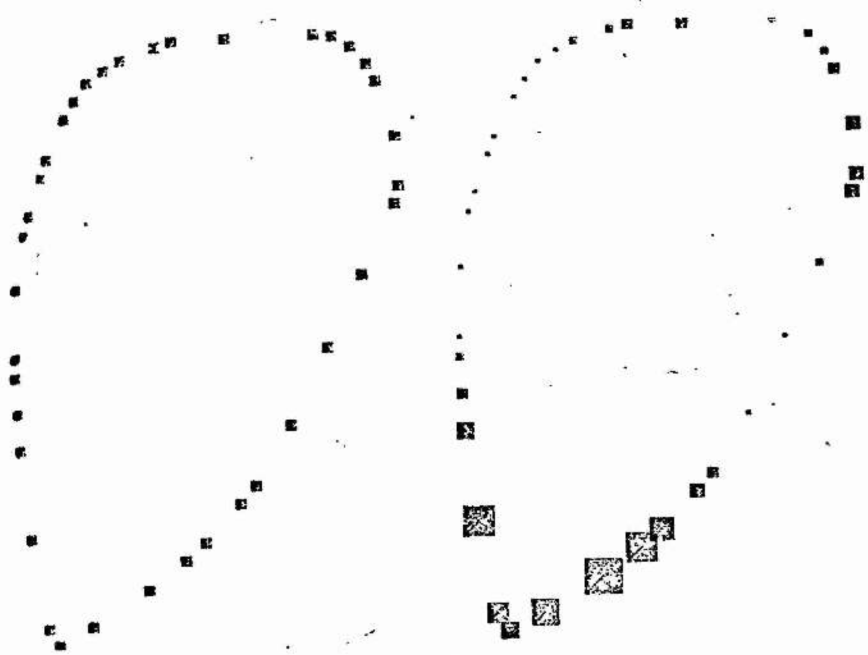
The association automaton is defined as a higher order processer which assesses these two basic functions of the perception automaton to provide more sophisticated processing of the sensory data input. It incorporates the perception automaton, but, in addition, has a memory and a facility with which to compare the content of its memory with the processed input pattern from the perception automaton. The nature of the pattern data in the memory store of the association automaton is in the form of stored configurations of sets of



(a) Original Pattern (b) Enhanced Pattern



(a) Original Pattern (b) Enhanced Pattern

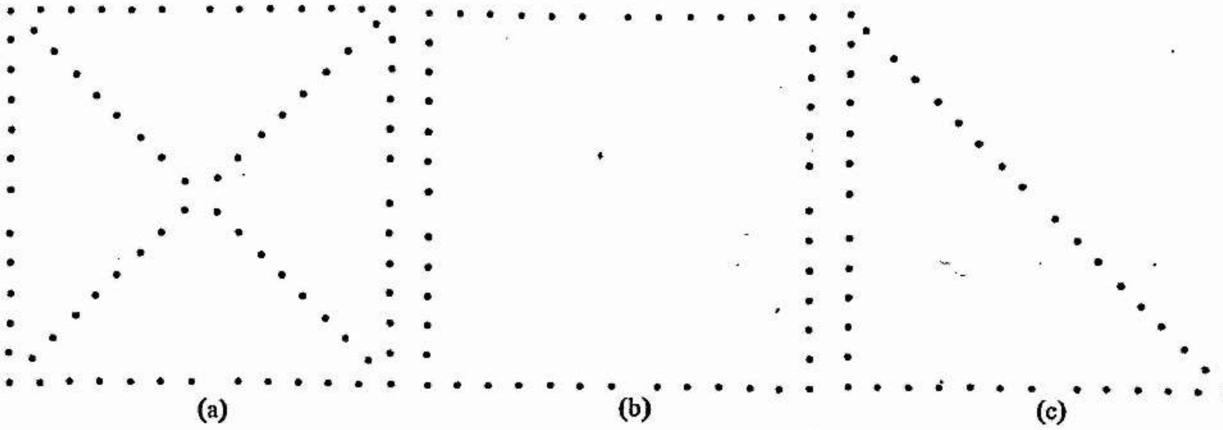


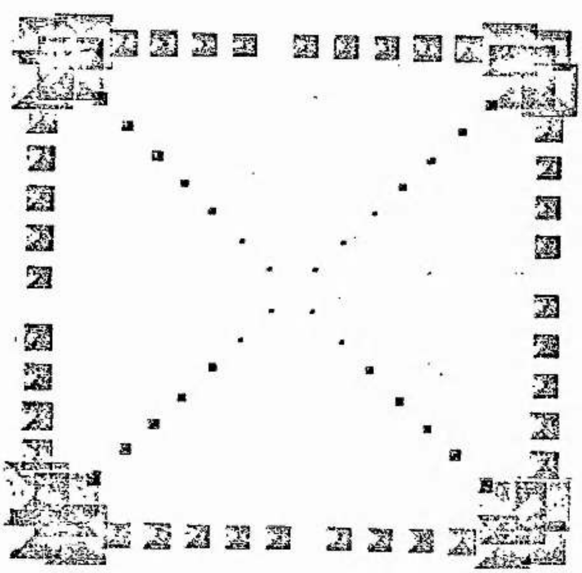
(a) Original Pattern Fig. 1. (b) Enhanced Pattern sensory patterns previously processed by the perception automaton. In other words, the information regarding particular patterns which is stored in memory is not stored in the form of a representation of all the first-order physical characteristics of the pattern, but in the form of a set of higher order characteristics of the statistical structure of the patterns. Thus, the comparative analysis of input data in terms of the information held in memory takes the form of the determination of those characteristics of the configuration of the processed pattern obtained by the perception automaton which are maximally shared with the various similarly derived pattern configurations held in the memory store.

Although these notions are primarily concerned with machine perception, it is considered by the present writer that they are clearly relevant to human information processing, particularly in the class of situations under consideration (p. 7). Any perception-memory system which operates not on the extracted higher-order complexity characteristics of patterns, but on a simple template matching of the direct physical characteristics of perceived patterns with similar "unprocessed" patterns held in memory, is inconceivable. For example, in order to recognise a square in any orientation, the memory store of such a system would have to contain images of every possible transformation of such a figure for every possible size of that figure. The number of such transformations and dimensions is, of course, infinite. These suggestions are congruent with what Welford (1968, p.162), for example, has termed "economy of perception", this requiring the "abstraction of constants" from the total input of sensory data encountered in space and over time in conjunction with the allocation of retention priorities to these constants. Moore et. al. appear to have, at least, provided a potentially viable paradigm for the extraction of such constants (e.g. "squareness") from visual patterns, and a methodology for the pro-active feedback of such data from memory to perception.

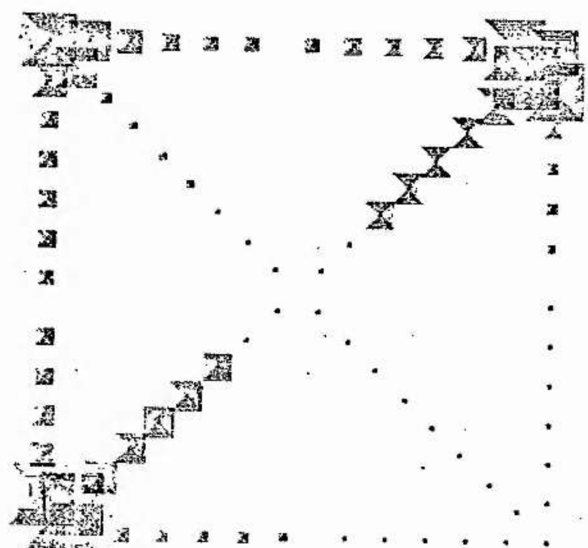
Thus, for their model Moore and Seidl describe examples of how information held in memory is able to influence the extraction and enhancement of particular features of a perceived pattern. If a particular pattern is held in memory it will enhance the perception of a similar pattern if that pattern is contained in a given stimulus field, even though that field may contain other patterns - i.e. the model is 'seeing' what it is 'looking for', or what it is 'expecting' to see. In particular, this aspect of the model provides a plausible basis for the consideration of individual (and cultural) differences in pattern learning and pattern recognition, the characteristics of each being largely dependent upon existing information in the memory store relating both to processing strategies and the patterns themselves. In terms of Moore and Seidl's notions, one can readily conceptualise 'individual differences' in pattern recognition performance between different association automatons, with different memory stores, in relation to their perception of the same visual information arrays.

An illustrative example of this process is shown in Fig. 2. According to Moore and Seidl, this new type of automaton illustrates the power of "a quite general conceptual framework for a theory of perception" (ibid., p.117). Although such statements must necessarily be treated with caution, the present writer considers that they are sufficiently worthy and provocative to extend their most significant implications





A diagramatic representation of the output of the association automaton when pattern (b) is "associated" with pattern (a).



Output of the association automaton with pattern A as input and pattern (c) as the memory element.

Fig. 2.

further in conjunction with concepts from other areas of cognitive psychology.

In the present context, the most significant implication concerns the reciprocal interaction of sensory perceptual information with perceptual information held in memory. Piaget (1969), in his elaborate discussion of what he calls 'perceptual anticipations' states that if the characteristics of an 'object' - for which may obviously be substituted the word 'pattern' - are taken to be a, b, and c, then c will be "anticipated" if a and b are perceived. In recognising familiar objects, writes Piaget, that is, objects (patterns) about which information is stored in memory, the perceiver will bring pre-implications and anticipations into play: "For instance, it would be very difficult to know if a subject had distinctly perceived the equality of the angles of a square or if the equality had been perceived only by implication from the global form ... above all, his explanations and transports will be guided by these implications when the perception is equivocal, for example, when the squareness of a figure is found to be in conflict with other factors." (ibid., p.191).

The conceptual parallels between these notions of Piaget's and the role of the association automaton of Moore and Seidl are clearly apparent. The present writer considers that further propositions may be derived from ideas such as these, which implicitly (Piaget) and explicitly (Moore and Seidl), highlight the possible role of the memory function in the operation of the perceptual system. This point is made most succinctly by Welford (1968, p.174). He observes that a result which occurs throughout Bartlett's work and a substantial amount of preceeding and subsequent work is that:

"Much of the detail which is apparently perceived is in fact inferred. It seems as if a schema which is imposed on incoming data brings a considerable amount of detail with it and this is incorporated into the resulting perception."

1.7 These notions are conceptually congruent with those of what is generally termed the "New Look" in perception, beginning after World War II and inspired primarily by the theoretical and experimental work of Jerome S. Bruner (1957a, 1957b). Bruner's (1957b) important and influential paper titled "On perceptual readiness" stressed the effect on perception of "readiness", "expectancy", or "set", on the part of the perceiver. The basic effect of set on perception is said to be as follows:-
In a situation in which a perceiver is given specific instructions to attend to only one of several attributes of a stimulus display, or in which he subjectively expects to perceive a particular attribute of a stimulus display (e.g. through previous experience), he is able to report his perception of that attribute more accurately than he would be able to do otherwise.

The basic proposition of the New Look perceptionists is that the perceiver's cognitive processes greatly influence the manner in which he perceives the world. According to Bruner (1957b, p.148), the "likelihood of occurrence of events learned by the person in the course of dealing with the real world of objects and events and the redundant sequences in which these are embedded" results in the person building a "model of the likelihood of events" (ibid), an activity seen as "achieving a minimization of surprise for the organism"(ibid.). Clearly, Bruner is placing great emphasis upon the existence and the role of a cognitive, constructive component in perceptual experience. Neisser (1967, p.15) employs the term "visual cognition" in this context.

The more detailed aspects of Bruner's ideas have been widely debated. For example, Neisser (1967, p.49) argues that "Bruner's claim that 'all perception is necessarily the end product of a categorisation process' must be rejected" because many cognitive processes, such as iconic storage, do not involve categorizing "to any serious extent" (ibid.).

Haber (1966) provides a comprehensive discussion of the historical development of the theoretical and empirical research into the nature of the effect of set on perception. However, the primary purpose of Haber's paper is an examination of what he argues are the two basic and dissimilar hypotheses that have been used to interpret the effect of set on perception.

The older of these two hypotheses, and the one most favoured by the 'New Look' perceptionists, (e.g. Dember, 1960; Postman, 1963), employs the concept of "perceptual enhancement" or "tuning." Thus, attending to a particular stimulus attribute "results in a clearer and more vivid perception of that attribute - it stands out more" (Haber, 1966, p.335). The feature enhancement process of Moore and Seidl's association automaton described previously (p.14) well illustrates this notion.

The second hypothesis is that set "has no effect on perception itself but only on some aspects of the memory trace or on response to that perceptual experience" (ibid.). According to Haber, there are three forms of this "response" hypothesis, viz: "(a) the set facilitates relevant responses by S, increasing the probability that S can identify the stimulus in his report; (b) the set causes S to report the emphasised attributes first, before memory of the stimulus fades, thus allowing those attributes to be reported more accurately; (c) the set modifies the organisation of the memory trace, so that the important attributes are remembered more accurately." (ibid.). Haber points out that these two basic hypotheses have wider application in perception and memory in addition to specific problems of set.

Relevant to this latter point, Gomulicki (1956), for example, considered remembering as an active, abstractive process and in a series of experiments on the immediate oral recall of verbal passages of varying lengths found that, in recall, a high degree of selectivity was shown in relation to omissions from the material originally presented. "Items omitted were regularly those which contributed least to the general meaning of the passage" (ibid., p.92). Gomulicki related subsequent recall of items to the distribution of attention during hearing of the original passage, stating that the items of content most attended to were those most clearly remembered.

Haber argues that the two hypotheses reflect "one of the most difficult distinctions in any analysis of perceptual behaviour." (ibid., p.336). The usual procedure of experimenters has been to assume that simply because the subject was reporting immediately what he had perceived, he was therefore performing a "perceptual" task. According to Haber, "there is a crucial difference between reporting one's experience and reporting the attributes of stimuli that one remembers seeing. One task is perceptual and the other deals with a memorial process" (ibid.). Haber emphasises that these must be conceptually differentiated and states that innumerable experimenters have failed to make this distinction. Consequently, much of the theoretical controversy in this area is a direct result of this confusion.

However, after evaluating the available evidence Haber's final conclusion is that these two hypotheses, which can both be supported by appropriate experimental evidence, are not incompatible but only alternative and often complementary. "There is no reason to doubt that both may be correct and occurring together." (ibid).

Such a conclusion would seem to support strongly

Reitman's (1970) arguments that perceptual and memory processes are too interrelated to separate and that the "conceptual differentiation" espoused by Haber is arbitrary and contrary to the functional nature of human information-processing performance. Certainly Haber's very strong emphasis on the primary role of verbal encoding strategies would be challenged by the more recent work of Paivio and his collaborators (e.g. see Paivio, 1971), together with current work on the power of picture memory (Standing, 1972).

Some of Haber's statements are questionable. For example: "Introspectively, it might be very difficult for an S to differentiate a rapidly fading memory from an image that was perceptually less clear." (Haber, 1966, p.331). If, as recent research suggests (Sheehan, 1972), the "memory" itself at a subjectively experiential level may well be an image, then there is no necessity to distinguish these notions. Further, Haber's claim that there is a "crucial difference between reporting one's experience and reporting the attributes of stimuli that one remembers seeing" is disputable for the reason that in order to report one's perceptual experience, or even to relate any stimulus to an experiential category there must be a dynamic memory component operating all the time.

Although the effects of set are well established, then, considerable theoretical controversy exists. However, on the basis of all the available evidence, it can be stated that, in information-processing terms, there is at least a two-way continuous flow of information involving the integration of information input from the visual sensory system and information held in memory. Obviously, the specific dynamics of this information flow may be dependent on a wide range of search, retrieval, encoding and decoding strategies, for example, and these may differ between subjects.

In a number of experiments (see Haber, 1966) there is clear evidence that, at the level of subjective conscious experience, information concerning the anticipated characteristics of a stimulus may be fused with partially processed sensory information from a stimulus display <u>which does not physically contain some of these expected attributes</u>. A good example of such a phenomenon is the experiment of Bruner and Postman (1949) on the perception of incongruity. In this experiment subjects expecting the tachistoscopic presentation of normal playing cards were actually presented on occasion with cards in which the colours of the suits were changed. Most subjects reported perceiving the incongruous cards normally, and, very significantly, some reported a "fusion" of the expected (e.g. black) and actual (e.g. red) colours for the particular card, seeing the card as "purple". Clearly, the visual characteristics of the expected playing cards can be completely specified from memory, having been overlearned through extensive previous experience.

Similar effects were shown in an important early experiment by Pillsbury (1897). In an extensive investigation of word reading, Pillsbury found that under certain conditions of expectation and context, subjects would report accurate letter-by-letter perception of words which were actually either misspelt, or which contained a "shapeless blur" in place of an original letter. The blurring effect was obtained by typing an 'X' over the original (ibid., p.342).

For subjects in these, and in similar types of experiments, to be able to consciously experience such composite perceptions there must be some kind of integration of information from the external, or 'real', stimulus display (otherwise subjects would not be able to identify correctly the pattern shown) and information about that pattern held in memory (e.g. with regard to the appropriate colour of a playing card).

1.8 If information from internal and external sources is integrated in this way, then it is a logical step to consider in detail a system by means of which this might happen, rather than simply to postulate that it does. The subjective phenomena of dreaming and hallucination provides irrefutable evidence that 'normal' perceptual experiences may emanate directly from the memory store. That is, subjects can experience clear, complete and dynamic 'pictorial' perceptions of their external environment without any external input through the visual sensory channels. Neisser (1967, p.120) states: "Even without any stimuli at all, dreams and hallucinations result in experiences which are phenomenally just like other perceptions."

The functional similarity of dream imagery and normal perception strongly suggests that, at the level of conscious experience, the two represent extreme ends of a continuum of the same basic process. Dependent upon a wide range of factors, such as time-sharing of attention, subjective probabilities of expected patterns, and stimulus clarity, the total information content of perceptual experience may, at any instant, be made up of <u>both</u> 'real' information from the external world and information from the memory store, with the contributions of each information source to the total perceptual experience being phenomenally indistinguishable from each other.

Direct support for this argument is provided by Dixon (1971). In discussing the common occurrence of phenomenal representation without the concurrent input of any external sensory information (e.g. as in dreams, imagery and hallucination), he states: "That recently blinded individuals continue to experience visual dreams, whereas these are not reported (Berger, 1967) by the congenitally blind, or those who lost their sight many years ago, seems to show very clearly that the system subserving phenomenal representation is one which is just as ready to accept information from memory as it is from current sensory inflow" (p.309).

This general notion is also indirectly supported by Antrobus (1968; Antrobus, Singer and Greenberg, 1966) who describes an information theory model relating to some of the operations involved in the unsolicited generation of "fantasy, imagery and other sequences of mentation which are not strongly 'directed'." In this model, both sensory-perceptual and non-perceptual events are assumed to be outputs of a "common limited-capacity cognitive operator" (p.423).

Thus, the phenomena of mental imagery appear potentially able to meet the requirements of the system under consideration.

1.9 Since the mid-1960's there has been a resurgence of psychological research interest in the field of mental imagery, and a number of investigators (e.g. Sheehan, 1972; Segal, 1972; Neisser, 1967) have argued in favour of a "functional similarity between imagery and perceiving" (Kessel, 1972, p.155). In the pre-Watsonian early years of psychology the primarily introspectionist study of the mind was a central field of study and "mental imagery was one of the most important concepts for the understanding of human behaviour"(Sheehan, 1972, p.xiii). Watsonian behaviourism, and the later neobehaviourism typified by the Hull and Spence schools from the 1930s to the 1950s dominated mainstream psychology, and mentalistic terms such as 'cognition' and 'imagery' "were still relegated comfortably to the world of the poet" (ibid.). Watson claimed that such concepts would "never reappear" in psychology (Watson, 1920, p.94).

As an integral part of the renaissance of cognitive psychology of the mid-1960's (Bower, 1970) a new style of thinking about imagery has emerged, dating from an important paper by Holt (1964) who wrote about imagery as "a long neglected topic just emerging from ostracism" (Holt, 1972, p.3). Kessel (1972, p.155) in a review of recent imagery research refers to imagery as "a dimension of mind rediscovered", and he examines the major methodological and theoretical issues emerging from this rediscovery.

A fundamental aim of this revival of interest in imagery and the field of cognitive psychology in general is to restore conscious experience to the status of legitimate data in psychological research. (Burt, 1962; Zener, 1958; Zener and Gaffron, 1962). Kessel (1972, p155) points out that, ironically, the best support for this general position is provided by Carnap, "a founding logical positivist and ... the father of operationism, viz: 'a person's awareness of his own state of imagining, feeling, etc... must be recognised as a kind of observation in principle not different from external observation, and, therefore, as a legitimate source of knowledge'"(Carnap, 1956).

Neisser (1967) stresses the notion that, like other cognitive processes, imagery is active, constructive and an integral functional component of the cognitive system as a whole. Kessel (1972), Sheehan (1972), Richardson (1969), Horowitz (1970) and Segal (1971) provide comprehensive reviews of the entire field of contemporary imagery research and theory.

1.10 Some particular experiments are of prime relevance to the development of the present proposition that conscious perceptual experience may be a combination of external sensory information and internal memory information. As described previously (p. 24) some studies have clearly demonstrated the fusion of some memory information with an appropriate primary visual sensory input. The converse, i.e. the assimilation of real sensory input into the construction of images has been recently demonstrated in a series of experiments by Segal (1972).

Segal's experiments were based on much earlier work by Külpe (1902) and Perky (1910) which was specifically concerned with the question of whether imagery could be dependent not only on information stored in memory, but also upon external sensory stimuli which happen to be present at the same time and which may be processed as part of the image. In Külpe's experiment subjects were asked to report on any "objective" or "subjective" events that they consciously experienced while they were relaxing in a darkened room. At intermittent intervals a square which varied in location, size and brightness was projected onto one of the walls of the room. Külpe observed a fusion or integration of this physical stimulus with the subject's imagery. He noted that "the final product was experienced as a complete and integrated event and often classified as subjective, but the observer could not analyse it back into its objective and subjective sources." (Segal, 1972, p.205).

Perky (1910) followed up Külpe's findings with a now classic experiment. Her subjects were simply instructed to "imagine a banana", (or a leaf, or a book) and to describe their resulting images. A yellow banana-shaped form was allowed to oscillate briefly in the subject's field of vision while he described his image. All the subjects "noted that the imaged banana was on end and not as they had been supposing they thought of it" (ibid., p.432). The results, argued Perky, show that the stimulus form was registered at a sensory level as it significantly affected the final appearance of the consciously experienced image even though the subjects were not aware at any stage that a supraliminal stimulus had actually been present. Perky concluded that such undetected but supraliminal physical stimuli may be "mistaken for and incorporated into an image of imagination, without the least suspicion on the observer's part that any external stimulus is present to the eye" (ibid., p.450).

Segal (1972) contends that if these findings of Perky can be replicated, then "it follows that stimuli may be determining, influencing, and altering images all the time and the image cannot be defined simply as an experience which occurs in the absence of a stimulus" (ibid., p.205). In 1964 Segal and Nathan reported a partial replication and extension of the Perky effect. However, although Segal and her collaborators ultimately failed in a series of eight separate experiments (in Segal, 1972) to achieve the dramatic effects reported by Perky, they consistently observed far more subtle effects on the image which led Segal to conclude that the "stimulus was at least partially processed, and was assimilated into the generated image according to specifiable principles." (ibid., p.207).

In this series of experiments the basic methodology was the same throughout. The subject was seated and his head covered with a vinyl hood onto which, unknown to the subjects, slides could be projected at varying brightness levels. Material either congruent or incongruent with the instructed image was projected onto the hood. Subjects' verbal descriptions of their images were tape recorded, and later transcriptions of these tapes were rated independently for stimulus assimilation content by five judges.

For the purposes of the present study, the important general result of Segal's experiments was that at a statistically significant level, visual sensory information input from a real physical source could be assimilated into a subjectively synthesised image, and that, in many cases, subjects could not distinguish the "subjective" and "objective" information components in the image, even in situations where they knew a physical stimulus *might* be present.

Further strong evidence that supraliminal stimulus information can be processed by subjects without their being aware of it is provided by the work of Corteen and Wood (1972). In this experiment certain nouns (city names) were first associated with the occurrence of an electric shock. These nouns were then embedded in material presented to the nonattended channel in a dichotic listening task. Using GSR measures, it was found that "shock associated city names gave rise to a significant number of autonomic responses *even though Ss were not aware of them*." (my italics) (ibid. p.308).

1.11 In summarising the previous discussion several main points emerge, and these are as follows:-

It has been clearly demonstrated that:-

(a) memory information may be incorporated into phenomenal perceptual experiences emanating primarily from real physical stimulus inputs; and

(b) physical stimulus information may be incorporated into phenomenal perceptual experiences emanating primarily from subjective imagery.

It should be emphasised that it is not being claimed that (a) and (b) always occur, but that there is evidence that they consistently can and do in certain situations. Evidence of this kind strongly supports the argument for a functional similarity, or continuity, between the mechanisms of visual imagery and visual perception (Neisser, 1967, p.95). It is also evidence for a two-way flow of sensory-memory information in perceptual experience, the direction of flow of the major component of this phenomenal information being dependent upon the global characteristics of the organism-environment situation.

As an example, it should be noted that in the global situation in which the organism is sleeping normally, there is no doubt that concurrent auditory, tactile and even olfactory external sensory stimuli are often <u>directly</u> incorporated into dreams, i.e. with little evidence of any symbolic cognitive transformation of this sensory information input. (Neisser, 1967; Dixon, 1971). However, although Dement and Wolpert (1958) have shown that level of illumination 'per se' may have some limited effect on the content of dreams, in the case of the normally sleeping subject, experiments have failed to demonstrate that articulated visual patterns presented during sleep are incorporated either directly or symbolically into dream imagery. For example, Rechtstaffen and Foulkes (1965) presented such stimuli (e.g. real objects, printed messages) to subjects who were sleeping with their eyes taped open, and their pupils chemically dilated. The results of this experiment produced no unambiguous instances of any representation of the external stimulus in the reports of subjects woken shortly after presentation of the stimulus. Rechtstaffen and Foulkes refer to the "relative functional blindness of the sleeping state" (ibid. p.1157).

This term "functional blindness" is also used, in a quite different context, by Kahneman, Beatty and Pollack (1967) in connection with the observation of perceptual deficit in subjects during performance of a demanding mental task. (see later, p.40). It is conceivable that these two identically named effects may be found to be qualitatively the same. For example, Antrobus (1968; Antrobus, Singer and Greenberg (1966)) has shown that increases in unsolicited stimulus-independent thought processing (e.g. fantasising, daydreaming, imagining) may also decrease the concurrent rate of gain of sensory information emanating from environmental stimuli. Dependent upon the amount of such wholly internally generated cognitive processing which may be occurring during the state of sleep, concurrent real, 'normal', visual sensory information input may be effectively almost completely suppressed.

However, as Dixon (1971) has discussed in detail, there are paradoxes involved in consideration of the global state of sleeping (e.g. the brain may show <u>increased</u> evoked potentials in response to certain types of external stimuli). Although consideration of the particular state of sleep is outside the scope of the present work, there may well prove to be common factors linking the various phenomena under consideration in this thesis with those of sleep.

Because of the years of neglect of imagery and because most important contemporary imagery research has been carried out only in the last few years, the possible role of imagery in other areas of human information processing has been completely ignored. If the role of imagery in normal visual perceptual information processing is as functionally important as is being suggested here, then any theoretical viewpoint in this area which does not consider imagery at all is inadequate. The consideration of a possible role for the imagery system suggests a new approach to more 'traditional' phenomena, such as vigilance, for example, and experimental work to be reported in this thesis illustrates the potential value of a cognitive approach.

1.12 The next stage of the development of the present theoretical position is concerned with the proposition that perception and memory are active, constructive and conscious processes. What is important at this stage of the discussion is not the precise nature of the constructive cognitive activity involved in perception, about which there is considerable theoretical controversy (e.g. Neisser's 'analysis by synthesis'; Bruner's 'perceptual categorisation'; various forms of feature analysis), but the implications of the concept of constructive cognitive activity itself. In spite of the continuing unresolved debate over specific points, there is at least full agreement among cognitive psychologists that perceptual-memory processes do involve active, constructive information processing, i.e. the subjective thought processes of the human perceiver impose some kind of structural organisation upon his incoming sensory input. The perceiver acts upon his sensory input, a process which involves thought processes, and is not a passive respondent to this input.

A further basic notion common to all cognitive theoretical positions is the idea of selectivity of attention to parts of the visual field. In Neisser's words: "Attention may be flexibly redistributed to parts of the visual field. To focus attention on a figure is to devote the lion's share of processing capacity to it." (Neisser, 1967, p.123). The significant concept here is the proposition that the constructive activity of perceptual information-processing may involve the utilisation of a high proportion of the total conscious information processing capacity of the cognitive system.

1.13 There is a very substantial body of research which has addressed itself specifically to the investigation of the fundamental nature, capabilities and limitations of human information processing performance. This particular area of research had as its origin the pioneering wartime investigations of human sensory-motor performance in tracking situations carried out by K.J.W. Craik. (see p. 4). The publication in 1947 and 1948 of two now classic papers by Craik, in which he reported the results of this wartime work and outlined his own theoretical ideas on the human operator in control systems, inspired a great deal of subsequent research into 'intermittency' in human sensory-motor activity.

The intermittency hypothesis had a long history in psychology, dating from a paper by Pillsbury in 1913. Craik's basic argument was that "the human operator behaves basically as an intermittent correction servo" (Craik, 1947, p.56), and the evidence for this was the periodic or "wavy" characteristics of the time record of errors made by human operators on tracking tasks which showed "a spectrum with a predominant frequency of about 0·5 sec., with a smaller cluster of frequencies from 0·25 to 2 sec." (ibid.) This error pattern was most clearly evident on the performance records of unpractised subjects, the overtly 'jerky' performance smoothing out with increased task practice.

The greater part of the research work directly concerned with Craik's theory of intermittency, (as against that concerned with more general areas of human information processing), has been carried out in the U.K. Kelley (1968, p.191) observes that, although considerable interest in central intermittency was aroused in the U.S.A. by the work of Fitts and his colleagues (e.g. Noble, Fitts and Warren, 1955), workers in that country have been cautious in adopting the intermittency hypothesis.

Detailed reviews of the theoretical and empirical developments in this field are provided in two books, by Welford (1968) and Broadbent (1971). Although many specific issues remain unresolved or inadequately investigated (Welford, 1967, p.19 - in Sanders, 1967), and the overall picture is a complex one, a number of firm general conclusions can be drawn on the basis of the results of over twenty years of intensive theoretical and empirical work.

In his 1971 book, Broadbent, after evaluating all the relevant data, affirms that the basic theoretical notions of what has come to be termed the "single channel hypothesis" are most strongly supported of any model of conscious decision-making in human sensory-motor performance. For the purposes of the present discussion, two broad propositions of this hypothesis suffice.

Firstly, it is hypothesised that the times taken to process data and monitor response action set an upper limit on the amount of information that can be processed in a given time. Secondly, the proposition that all conscious decision making is central and sequential is important to the present argument. The possibility of the human operator being able to process independently two separate simultaneous streams of information in parallel is "still an open question", states Broadbent, but he concludes that "one cannot feel that there is any evidence for independent processing at present." (Broadbent, 1971, p.314).

Dual task research has shown that inter-task interference occurs when two tasks are performed simultaneously, particularly at the subject's maximum level of performance in the particular dual-task situation. (Welford, 1968, p.132). Further, all conscious control decisions concerning both task performances are made one at a time, and are made sequentially, the decision processes for each task capturing the single channel to the exclusion of all other information-processing for the entire time interval required for that decision. Thus, although ballistic motor movements involved in the simultaneous performance of separate tasks obviously may take place in parallel, the separate information streams involved in the control of each task are <u>not</u> processed in parallel, conscious attention alternating between them.

In addition to the processing of information predominantly derived from external sensory sources (e.g. as in the performance of a tracking task), the human cognitive system is capable of the autonomous generation of conscious thought processes in the absence of any relevant external sensory input. If all conscious information processing is centralised, as the evidence suggests, then decisions involving internalised cognitive processing should capture the single channel in exactly the same way as information processing relevant to the performance of external tasks. Therefore, irrespective of the nature of the task, i.e. internal or external, intertask interference should take place between any set of information-processing tasks which the subject is attempting to perform simultaneously at a high level of performance. Under these conditions, interference should take place between two external tasks or two internal tasks or, most significantly, between an external and an internal task. Thus, a subject performing a complex sensory-motor task, such as driving a motor car, for example, and simultaneously attempting to perform a mental task should experience interference. Experiments on subject performance in this particular situation show that this theoretically predicted inter-task interference does indeed occur (Brown and Poulton, 1961; Brown, 1962, 1965a, 1965b).

Kahneman argues that all information-processing activities "apparently draw upon a common pool and performance of multiple tasks therefore requires proper allocation of limited resources" (1970, p.121). Clearly, any kind of cognitive processing under conscious control, e.g. thinking, imagery, involves the capturing of the hypothetical single channel.

1.14 If the cognitive component of perception is the conscious, constructive decision-making process claimed by Neisser and others (see p. 34), then the specific task of visual pattern perception should be susceptible to interference from other cognitive information-processing tasks performed at the same time. However, our ongoing conscious stream of perceptual experience is not continually subjected to intermittent interruptions as a component of the system dedicated to some other simultaneous purpose captures the single channel. Subjectively at least, we do not appear to stop perceiving our environment while engaged in thought.

For this reason, the theoretical propositions developed in preceeding sections concerning the role of the imagery system become even more important. The suggestion is that during learning of novel perceptual layouts, the organism normally devotes all processing capacity to this function. However, once the relevant patterns have become overlearned, i.e. able to be completely specified or synthesised from information held in the memory store, the information-processing capacity devoted to the function of perception in situations involving these familiar patterns may be significantly reduced. The conscious analysis of real sensory input need only proceed as far as is necessary to confirm the presence of an expected pattern, the remaining information necessary to complete the particular perceptual experience coming from the memory store. In this way, in familiar environments, the cognitive information-processing load involved in the analysis of sensory input may be minimised, thereby freeing spare capacity for the performance of other tasks, as for example in the case of thinking while moving about in a familiar environment.

It would obviously seem logically and adaptively appropriate that the visual perceptual system should not be entirely and continuously devoted to the analysis of sensory input, and that the various time sharing parameters of this limited information-processing capacity should be variable according to the transitory requirements of particular situations. If 'attention' at any instant in time be defined in terms of the information actually being processed in the single channel at that instant, then attention becomes a cumulative measure, and the 'amount of attention' allocated to one task is measured in terms of the proportion of the total amount of information processed over a given period of time which is devoted to that task. In the terms of the present discussion, where there is a specific requirement for accurate perception of what may be a familiar environmental pattern, then the proportions of total processing capacity will be reallocated according to that requirement.

This kind of attentional control is very commonly applied in everyday life (Kahneman, 1970). "Thus, the experienced driver will normally interrupt his conversation while making a turn into the traffic, but may continue it while making a less dangerous turn. The transition is smooth, effortless and very rarely involves a conscious decision. As far as I know, even speculative efforts have not been directed to the question of how the system works" (ibid., p.121). The theoretical and experimental research reported in this thesis is concerned with some detailed aspects of this system.

1.15 According to the present arguments, the deficit in the processing capacity available for pattern perception of familiar patterns caused by the concurrent performance of a mental task will be compensated for by the utilisation of the imagery system. The resultant perceptual experience should be normal and complete. However, in a multiple-task situation in which what is being experienced perceptually is primarily composed of memory-derived information, with a minimum of processing of sensory information, the subject should fail to perceive transitory visual events or incongruities occurring within that part of the real visual information array which is not being processed at the time.

Clear evidence that this is indeed the case is provided by Kahneman, Beatty and Pollack (1967) in an experiment investigating perceptual deficit during a demanding mental task. Subjects in this experiment performed two tasks simultaneously, these being a digit transformation task and a detection task. A string of four digits (e.g. 8340) was presented auditorily and the subject responded verbally with another string (9451), adding 1 to each digit he had heard. These digits were presented at the rate of one per second and the subject had to respond at the same rate. At the same time, the subject monitored a visual display which flashed letters at a rate of five per second. The subject had to report after each trial whether or not the letter K had been among those presented. Performance in the dual task situation was compared with performance on both tasks performed separately.

Subjects were significantly more successful in the detection task when the transformation task was not required, and false positives were significantly more frequent in the detection task alone. An important finding was that the subjects' ability to detect signals varied continuously over the 8 seconds of the task in parallel with an independent physiological indicator of processing load (viz: pupillary dilation). Analysis of the patterns of error data led Kahneman to conclude that the effect was "not a failure of memory, but of perception" (Kahneman, 1970, p.121) - i.e. it was unlikely that subjects clearly recognised the target when it was actually presented and then forgot all about it.

Kahneman, Beatty and Pollack state that the subjects in this experiment "were to some degree functionally blind when they were engaged in thought" (Kahneman et. al., 1967, p.219). Such a statement is of extreme importance to the consideration of the applied situations to which this thesis is addressed, and the relevant implications will be discussed at a later point.

The theoretical ideas outlined and developed in the preceeding discussion both predict and explain the results of Kahneman, Beatty and Pollack. These investigators do not discuss the question of what the subjects are actually experiencing perceptually at the times when they miss the target.

1.16 In developing a theoretical approach involving pattern perception, the problem of the definition of a 'pattern' must be resolved. The problem central to any theory primarily concerned with cognitive aspects of pattern recognition, that is the problem of feature analysis and feature extraction (Parker & Moore, 1972, p.59) remains unsolved at the present time. The notion that there are within visual patterns sets of "objective features" which will be extracted by all human perceivers may not hold at the cognitive level. There are various clear physiologically defined specialised feature detectors in the visual system, involved in stereopsis, movement, contour, line, depth etc... In a recent review article, Gross (1973) notes that the visual areas in the monkey brain have now been mapped in some detail, but above a particular level the perceptual process becomes primarily a complex cognitive one, which cannot be 'mapped' physiologically.

It appears to be the case that the specialised sensory receptors of the visual system do provide a primary set of fundamental data forms on the basis of which the organism can analyse visual information input at a higher level, and that this primary sensory organisation is the same for all humans. However, what differs between subjects is what the individual cognitive system elects to do with the information potentially available from these peripheral feature detectors. Whatever the particular 'significant' features of a visual information array which are selected and used in perception might be, they may ultimately be a function of a particular individual form, or style, of cognitive processing strategy. The possibility must be acknowledged theoretically that these strategies may vary considerably between subjects, and within subjects.

A further difficulty is whether or not a visual information pattern may be arbitrarily defined, at some level, as a set of <u>discrete</u> "features", whatever these might be.

Visual information might well be encoded and stored in some analogue rather than digital form and, in spite of the existence of much computer-based research favouring digital processing, the possibility of full or partial analogue processing must at least be regarded as feasible until there is definitive research evidence either way.

These considerations raise critical problems for any theoretical model of perception and memory. The effectiveness and generality of the model at a cognitive level must not be limited by, and dependent upon, the correctness or otherwise of certain assumptions concerning as yet unresolved questions about the nature of pattern recognition. If we cannot state unequivocally which 'features' of visual information input different subjects select as 'significant', nor whether these sets of features are continuous or discrete, nor what are the precise encoding, processing, storage and retrieval strategies involved, what can be truthfully and usefully said theoretically about this problem?

There is a solution to this theoretical dilemma. Consider a complex visual pattern which a subject first memorises and unfailingly recognises on subsequent encounters. The picture or pattern can be defined simply as a quantity of information of some kind. Clearly it is at least this.

If we limit our definition to this very basic, but true statement, the theoretical difficulties raised by still unresolved problems such as feature detection and analysis, the precise nature of the optic array, and the possibility of vast individual differences in processing, may be bypassed. It becomes possible to discuss patterns with some degree of generality.

In order to recognise reliably the same visual array at any subsequent time, a subject must have processed and stored at least some proportion of this visual information, whatever that particular subject's individual processing strategies might be, and however much it may be different from other subjects' strategies.

It is emphasised that the concept of a 'quantity of information', as it is used in the present context, does not refer to 'information' in the formal mathematical communication theory sense (Shannon and Weaver, 1949). As noted earlier (p.5), the application of these formal concepts to the complex cognitive problems of pattern perception and recognition has met with only limited success, and the 'irrational' way in which mathematical communication theory has been applied by many psychologists in the investigation of human performance has been strongly criticised by Laming (1968, Ch. 1), for example. Garner (1962) points out that attempts to utilise formal information theory to determine an unequivocal constant maximum information-processing capacity for the human subject, in terms of 'bits' of information, have not been successful. A large number of factors, such as instructional 'set', overlearning of verbal material and of ballistic movement patterns, 'grouping' of responses, stimulus-response compatability, and semantic properties of messages, are not amenable to arbitary quantification in terms of 'bits' of information.

Broadbent (1971) states that the emphasis in this area of research has shifted from the deterministic approach of the investigators of the 1950's to the present probabalistic approach. The inapplicability of the formal mathematics of information theory to anything but the simplest situations has resulted in the term now being generally used in a manner closer to its intuitive or everyday sense. Moray (1967), Welford (1968) and Broadbent (1971) use the term 'information' more in a conceptual, non-specific sense than purely as a term of measurement. The present use is close to the term 'information' as it refers to computer programming, (i.e. the general processes of <u>manipulation</u>, rather than measurement of information).

Although the broad concepts of the "information sciences" (Neisser, 1967, p.7), which include formal communication theory, systems analysis and computer programming, have been of the utmost significance and usefulness to modern cognitive psychology, Neisser argues that "the upshot of more than a decade of research is that information measures have little or no direct relevance to performance in most cases" (ibid. p.112).

In the present thesis, then, in the absence of any suitable objective metric to quantify precisely complex perceptual information, the concept of a pattern as a 'quantity of information' is employed without reference to systems of units. As stated earlier, because it is a fact that patterns may be remembered (i.e. that information from the pattern is processed), we may speak meaningfully about the 'total information content of a pattern' as a hypothetical quantity which may include semantic aspects, and, although we cannot as yet 'measure' this in terms of some arbitary scaling system, we may clearly speak about <u>proportions</u> of this total quantity of information.

It may be that different patterns represent different absolute quantities of some form of total pattern information, and that the <u>same</u> pattern may represent <u>different</u> quantities of information to different subjects. However, because the present concern is only with <u>proportions</u> of total information, which does not involve units of measurement, it becomes possible to consider information processing performance referent to different complex patterns, and to different subjects, in a manner which facilitates direct comparisons on the basis of this common factor.

Consequently, when patterns are defined in this way it is proposed that the common factor linking similar subject performances may be considered purely in terms of proportions of pattern information utilised in various similar circumstances. In the following discussion, the notion of a 'pattern' is conceptualised in this manner.

CHAPTER II

The following chapter summarises and extends the basic theoretical ideas outlined and developed in Chapter I.

2.1 In familiar environmental contexts where the probability of occurrence of perceptual patterns already stored in memory is extremely high, it is postulated that the analytical requirements of the perceptual system with regard to the sensory input from such contexts are greatly reduced. To illustrate this notion at an elementary level: If the information content of a sensory pattern P_S is some quantity Q_S, then, if the subjective probability of occurrence of P_S is high, confirmatory feedback as to the presence of the expected pattern P_S need only involve the processing of a relatively small proportion of the total relevant sensory pattern information Q_S. In contrast if P_S were a novel pattern (which might or might not become familiar), the perceptual system would have to process and possibly transfer to the memory store the total amount of sensory information Q_S. Thus, under the two conditions the information-processing requirements, or loading, of the perceptual system are quite different. A third possibility must also be acknowledged. That is, where the probability of occurrence of P_S is high and it is familiar, the subject may still, however, direct his perceptual system to the detailed analysis of P_S.

It should be emphasised here that the concept of 'a proportion of the total quantity of information' is not logically linked to any <u>specific</u> proportion for a given pattern.

Rather, the idea is that on repeated encounters, or prolonged exposure, to the same expected sensory pattern in the same context, the subject may, in each case, or time period, process the same proportion of the total available sensory information, but this proportion may well be referent to different aspects of the same real sensory pattern. In this way, over a series of continuing re-encounters with the same perceptual layout the accuracy or veridicity of all the memory information concerning that pattern may be continually checked and progressively updated if necessary, even though at each encounter only part of the real sensory information is being processed. This proposition has obvious implications for the concept of "rehearsal" of information in the memory store, (e.g. Welford, 1968), a process which is hypothesised as increasing the resistance to decay of the memory trace of these items. These implications will be further discussed at a later point.

2.2. In part, these ideas are conceptually similar to Vicker's (1970; 1972) suggestions regarding the mechanisms underlying the emergence of a perceptual organisation. Vickers proposes that the process is mediated by an "optional stopping" mechanism, and that this mechanism is of the accumulator type. Vicker's notions are concerned with responses to particular figures or patterns, the idea being that the observer operates on a distribution of signal differences relating to the pattern elements. The observer steadily inspects these positive and negative differences one at a time until some criterion, k, is satisfied. Vickers suggests that this criterion k actually used is an accumulated magnitude of positive or negative signal difference. The present ideas are related except that the primary concern is with the encoded information content of familiar patterns. The notion of a criterion is relevant in the sense that, for decisions to be taken concerning the presence or absence of such a pattern, a criterion relating to the amount of information in the sensory pattern which must be processed in the given context to confirm the presence of the expected familiar pattern must be met. Once this criterion is reached, analysis of the sensory information need not continue.

To summarise, if there is no requirement that the perceptual system completely analyse a given sensory pattern, then it need not do so. It may perform only a rudimentary and partial analysis of the external sensory input, processing only that proportion of the total definitive information about that pattern subjectively considered necessary to infer the remainder. In such cases, the total information flow within the organism concerning a familiar pattern may be the resultant of a small amount of information coming directly from the external environment and the bulk of the information coming from the memory store. The critical notion being put forward here is that there is firm empirical evidence for the existence of a system by means of which information in memory may be experienced perceptually, and this is the imagery system. Rather than lying dormant for much of the time and only being utilised in specialised, purely imagery, functions such as dreaming or thought, it is proposed that the imagery system is a 'live' system which is constantly active. Through the functional integration of memory and sensory perceptual information, it makes available information processing capacity which enables the human organism to move about in familiar perceptual environments without having continuously to devote its entire information processing capacity to the analysis and recognition of sensory patterns. Bartlett stated in 1932 that "it is clear that images have fundamentally important parts to play in mental life" (Bartlett, 1932, p.215), an opinion that was "hardly popular" (ibid.) at the time. Current imagery research indicates the correctness of Bartlett's view.

Thus, an important concept proposed here is that for given patterns and situations the nature of much information flow within the human perceiver may be largely in the form of a closed loop in which, according to particular contexts, information in memory concerning particular patterns is recirculated, via the imagery system. This information from the memory store is utilised to enhance or augment the input from the perceptual system in a manner conceptually similar to that described by Moore and Seidl.

2.3 The question may be raised as to why, given the ideas outlined in the foregoing discussion, it is necessary to postulate that information in the memory store is integrated with partially processed real information. Aside from its potential importance for the concept of rehearsal of information in memory, the proposition would appear intuitively sound on the basis of introspective evidence that there are no consciously apparent 'gaps' in our continuing visual perception of patterns, which would necessarily be the case if the sensory input of familiar patterns were only partially analysed and relevant memory information concerning these patterns were not utilised to enhance or complete what is consciously 'seen'. If, as Neisser (1967) suggests, perception and memory are constructive processes, then conscious thought is clearly involved in the perception of patterns. It is proposed that the <u>part</u> of this process involving the accessing and recirculation of stored memory information involved in the image enhancement of expected familiar patterns is overlearned, and, therefore, largely automatic, requiring little or no conscious direction, as in the case of ballistic motor movements in particular skills. Bartlett (1958) has considered high level cognitive processing as a skill in this sense.

In his 1963 paper on "the multiplicity of thought", in which he presented theoretical concepts later updated and refined in his definitive book "Cognitive Psychology", (1967), Neisser proposed that people "commonly or constantly think about several things at once" (p.12). This notion apparently contradicts the "widespread conviction" of both laymen and psychologists that "it is impossible, or at least unusual, to do even two things at once" (ibid.). Neisser resolves this apparent contradiction by proposing that, although this belief is valid, it shows "only that we cannot be <u>conscious</u> of two complex processes together." It is postulated that certain kinds of thought processes may occur concurrently with a conscious main stream of thought <u>outside</u> of consciousness. According to Neisser, if a process is "automatic" enough to be outside of consciousness, it may occur in parallel with conscious thought processing. In the context of the present thesis this idea supports the notion put forward here that the thought processes involved in the integration of memory and sensory perceptual information may be largely automatic, and consequently take place outside of conscious awareness.

It is postulated that the information-processing load involved in the constructive analysis of sensory information is greater than that involved in the generation of images of existing stored patterns, even though the patterns involved and the resulting perceptual experiences may be the same. The basis for this assumption is that the information stored in memory is already processed according to the subject's various strategies and does not involve the utilisation of the usual sensory receptors at any point. In contrast, the analysis of real sensory information requires at least the necessary additional stage of transducing and processing the real sensory input into whatever ultimate form in which it is utilised and stored.

It follows from this argument that, in the case of the generation or synthesis of novel images, the processing load is greater than that involved in the synthesis of over-learned patterns, but it is still less than the perceptual processing load involving the analysis of real sensory input, because the synthesis of even novel images is based on internalised information content which does not require the additional stage of sensory information processing.

2.4 From the theory outlined above it follows that the informational loading of that part of the human cognitive system involved in visual pattern perception is variable according to either, or both, of (a) the information processing requirements dictated by the degree of familiarity of the pattern, and, (b) the subjective direction or conscious focussing of the sensory analysis facilities of the perceptual system by the perceiver. Thus, if it is accepted that the various cognitive processes are interdependent, interrelated, and interactive, (e.g. Bartlett, Reitman, Hunt, Piaget etc...), and that there is strong experimental evidence to suggest that the conscious information processing capabilities of the cognitive system as a whole are limited, (e.g. Welford (1968); Broadbent (1971)), then reduction in the information processing requirements of the system component concerned with conscious analysis of direct sensory input data will provide additonal information processing capacity capable of utilisation by other components of the system.

This point may be more clearly illustrated by reference to a computing system - provided, of course, one accepts Hunt's (1971) claim as to the validity of an analogy between a human being and a computing system, (a claim disputed by Neisser, (1972)). Consider the now typical situation of a large central digital computer simultaneously accessed by a number of remote terminals through which information may be read in and out. The greater the number and utilisation of these remote terminals, (i.e. the larger the amount of information flow connected with their operation), the greater is the proportion of the information processing capacity of the large central computer utilised in simply organising and structuring the information flow of these terminals. This means that the remaining processing capacities of the central computer available for the analyses and manipulation of the information content of the terminal inputs is greatly reduced. Reduce the loading from the peripheral terminals, and the "thinking ability" of the computer is increased. One way of reducing this loading from the terminals is to decrease the analytical requirements of the flow of information from the terminals by either reducing the actual input and/or pre-processing this input so that the information is partially organised to begin with.

This latter point may be further illustrated by reference to the work of Posner (1962; 1965). Posner notes that most tasks, such as reading a book, listening to a lecture, forming a concept, or solving a problem, require the subject to "take in information, to transform it in various ways by means of selection, classification and combination, and to store the product of these operations" (p.197). Such serial tasks, in which emphasis is placed upon the storage of transformed information appear to be "most representative of intellectual performance" (ibid.).

In the following discussion it should be noted that Posner is using the term 'information' in the formal, communications theory sense. (see footnote, p. 55).

Posner describes three types of transformations according to their informational properties, based upon the relation between input and output information required for perfect task performance. The first type of transformation is termed 'information conservation', in which the subject must preserve all of the information input in his response (e.g. as in reaction time and memory span tasks). Secondly, 'information creation' tasks are those in which the information output must exceed the input if the subject is to carry out the task (e.g. as in word-association tasks). Thirdly, 'information reduction' tasks are all those in which "the subject is required to map more than one stimulus point into a single response" (ibid.). For example, addition, classification and selection are information reduction tasks. It is this third category of transformation with which Posner's experiments have been primarily concerned.

Posner's hypothesis is that "the difficulty or amount of mental processing required in an information reduction task is directly related to the amount of information reduced" (p.199). He tested this hypothesis in the following way (Posner, 1962): In a series of experiments, constant sets of 8 numbers, comprised of digits randomly selected from the range 1 to 64, and therefore representing 48 bits of information, were presented auditorily to subjects, at interstimulus intervals of between 1 and 4 seconds. Six different information-reducing transforms were investigated, varying from 0 to 40.3 bits. These tasks ranged from simple recording of the number presented (an information conservation task) to various combinations of addition, and classification into such categories as 'high and odd' or 'low and even'. Posner found that "the results of several different experiments showed that the greater the information reduced between input and output, the more performance declined with increasing speed. The relation between rate of decline in performance and information reduction was roughly linear" (p.199).

In general terms, Posner's argument is that the amount of information to be reduced between input and output is representative of the amount of mental processing required by the task. Thus, it follows that, if a given task input may be partially pre-processed, so that a smaller amount of information must be reduced in the transformation to output, then less processing capacity must be utilised in performance of the task. Therefore, by reducing the amount of information reduction required by the task in this way, the thinking capacity available for concurrent performance of other cognitive processing tasks, (e.g. problem solving, rehearsal in short-term memory tasks), is increased. Posner's work provides a useful experimental illustration of the computer system analogy discussed above.*

This point is emphasised to illustrate the ability of the present theory, as it has been developed so far, to describe a perceptual system in which information in a memory store may be dynamically and continuously utilised to reduce the analytical information processing requirements of perception, thereby providing additional capacity for potential utilisation, (e.g. for thinking), by other components of the system. By considering aspects of total system performance in controlled situations it is possible to test these propositions experimentally. This methodology will be described later.

In outlining the information processing organisation of the visual system Hunt (1971) states: "It does not defy intuition to say that man sees much and thinks little." This is too dogmatic a statement, particularly in the light of the present approach. It fails to acknowledge a most important possibility raised by the present argument, and it is felt that Hunt's statement, as it stands, misses the point. In terms of the present model, such a statement should read: "(i) When man is seeing much he is thinking little, and (ii) When man is thinking much he is seeing little." Here, of course, the verb

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* Note that, although Posner is using 'information' in the communication theory sense, and measuring this quantity in 'bits', a procedure susceptible to the considerable limitations outlined earlier (p. 44), he is restricting this quantification to simple classifications and clearly definable sets of operations. He acknowledges the extreme difficulty of applying such measurements to the study of complex intellectual tasks, in which the sequence and complexity of the steps through which the subject must pass to perform the task cannot be precisely specified.

'see' is referring to the perceptual analysis of sensory information from the immediate environment. We may, in thought, 'see' images without actual reference to the sensory signals from the external environment in which it is highly probable that such images are contained.

2.5 The present theory thus considers the human being in a way rather different from traditional information processing approaches. In a manner analogous to the development of what has been termed the "social psychology of the laboratory" (Bickman and Henchy, 1972; McGuire, 1967; Ring, 1967), it is worth considering the possibility that such a development may have taken place in other "hard" fields of psychology. It is possible that removing the study of perceptual behaviour from natural contexts changes its very character, and thus the elements studied may be very different from their counterparts in the field situation. Reitman (1970), in his discussion of the laboratory investigation of memory by artificial and contrived tasks, and the role of subjects' strategies in the performance of such tasks, would certainly appear to support this argument. The simplification of memory models and the impossibility of decoupling the memory process from the cognitive system as a whole, together with the nature of the laboratory tasks typically used "eliminate the everyday context of memory", argues Reitman (ibid., p.473). Welford (1968) also lends strong support to this view, stating that: "Perception in everyday life is ... much more complex than it is with the single objects or groups of objects used in laboratory experiments." (p.178)

The present theoretical position suggests a conceptual framework for the consideration of the human being in his normal environment. Where the environment is familiar he may, for much of the time, exist in a state where the sensory analysis facilities of his perceptual system are simply 'idling' within some range of minimum activity level necessary to maintain them in a viable state of readiness. Such a state of readiness involves periodic or partial confirmatory sampling of sensory data from the 'external' world. The information components involved in augmenting this partial or periodic analysis are continuously 'recirculating' via the imagery system. Thus, the human can easily move about in this environment 'thinking about something else.' In new environments, or where the human elects to analyse familiar patterns in detail, the situation is, of course, different. It is hypothesised that, in familiar environments, the organism is, in effect, for much of the time 'inward looking' and 'seeing' what is in memory.

If the proposition concerning a minimum level of activity holds, it follows that when activity falls below this minimum, the perceptual systems may be automatically activated and analysis of the sensory environment commences, whether or not the environmental sensory pattern at that time is familiar. This analysis ceases again when the required level of activity is reached. In general terms, a basic idea of the model is that if we stop thinking we tend to inspect our sensory environment, and, intuitively this would seem a reasonable statement. Conversely, if we are engaged in internalised thought, we tend to analyse less sensory data from our environment. This proposition has been tested and verified experimentally. (see Chap. III).

2.6 It is emphasised that, from the conceptual approach of the present theory, it follows that pattern-recognition is context-dependent. If the functional role of pattern information held in memory is as it is proposed here, then because the probability of occurrence of familiar patterns is inseparably related to the organism-environment contexts in which they normally occur, the nature of the process is determined by this fact. Thus, even in the case of novel or unfamiliar patterns, the nature of the perceptual analysis imposed by the subject upon sensory data input from his environment is determined by information held in memory.

In the transference of sensory pattern information to memory, or in the initial interpretation of novel sensory patterns, it is proposed that the basic control function of the cognitive system is to maximise the sharing of higher order pattern information characteristics derived from the sensory data with appropriate sets of similar characteristics already in memory. In other words, according to his cognitive presuppositions and expectations in relation to any given situation, what is in memory largely determines which attributes of sensory patterns are sought out by the perceiver - i.e. in order to make sense of any sensory information input, he must have in memory a set of internalised referents by means of which this input might be evaluated. Conversely, failure to utilise the appropriate sets of internalised referents may lead to failure to perceive organisation of any kind in the stimulus array.

Leeper's (1935) classic experiments illustrate the essence of the present argument. Subjects were asked to identify figures such as those in Fig. 3 . When told what to

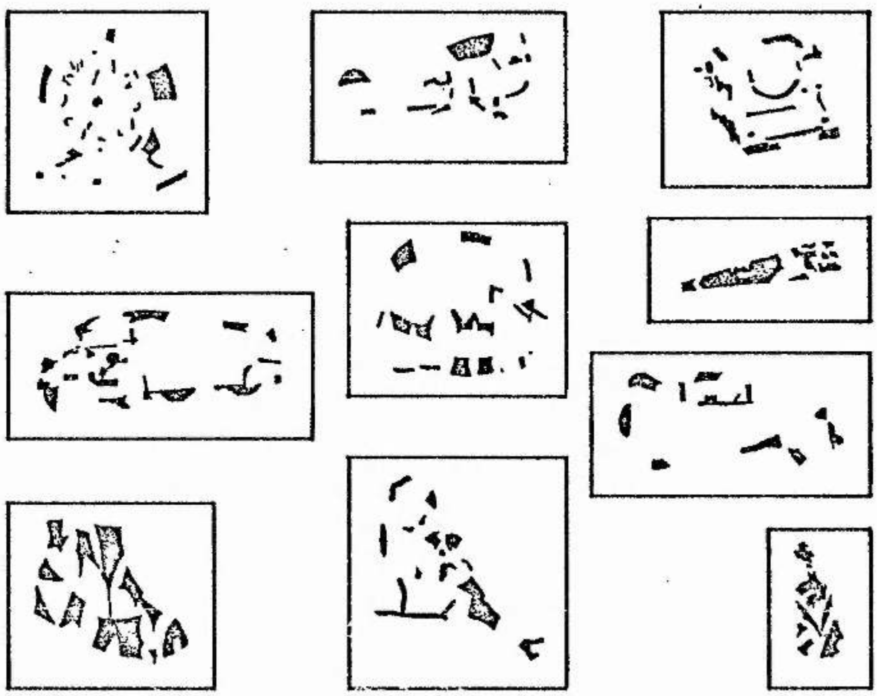

Fig. 3: Figures used by Leeper (1935).

expect (e.g. "it is a musical instrument") subjects were more often able to structure the pattern and recognise the particular item. We are here, of course, again considering the phenomena of perceptual sets, and, as Neisser (1967, p.61) points out ".. any theory of pattern recognition must reckon with them."

Further empirical support for the theory may come from clinical evidence. Subjects who have suffered injury leading to sudden partial or complete loss of sensitivity in areas of the visual field may not be consciously aware of this condition, at least in normal familiar visual environments. (Gedye, personal communication,1973) Under such conditions, provided the appropriate memory systems are unaffected, information held in the memory store, previously obtained and stored via the intact visual system, is constantly utilised to present normal and complete perceptual experience.

This area appears worthy of investigation as, if memory information were not being utilised in the manner proposed by the present theory, such subjects should be aware of decay in parts of the visual field when fixating a visual array with little eye movement. It would be predicted by the theory that in certain kinds of novel pattern recognition situations comprising patterns and pattern characteristics not in memory, conscious awareness of some visual damage might become subjectively apparent.

2.7 There follow some preliminary comments on the experimental investigation of the model.

In addition to the substantial direct and inferential support for the present approach provided by the existing literature, it is possible to test directly some specific aspects of the model. The problems connected with artificiality of the laboratory situation can be minimised by utilising an experimental configuration employing materials and cognitive functions relevant outside the laboratory. For example, visual stimulus material can be in the form of well overlearned complex patterns such as photographs of highly familiar objects and scenes.

The initial and most important stage of the investigation is to test the notion that much information is recirculated from the memory store utilising the imagery system when there is no requirement for comprehensive analysis of the direct sensory perceptual input and, consequently, the capacities of the central mechanisms are freed for other cognitive purposes. It is considered that this aim can be achieved by a controlled investigation of subjects' performance in a task situation incorporating the simultaneous recognition of complex visual patterns and the performance of an internalised cognitive task involving considerable utilisation of the subjects' conscious thought capacities.

In this way, by forcing the subject to attempt to perform the two tasks simultaneously, he is prevented from devoting his entire processing capacity to one task, or to the other.

Welford (1968, p.132) points out that it has long been known that, where subjects are required to perform two tasks simultaneously, "the speed or accuracy of one or of the other or of both is likely to be lower than when the tasks are carried out separately." In some contrast, from the premises of the present theory it can be hypothesised that this need not necessarily be the case where one of the two tasks is concerned with the cognition of highly familiar patterns in contexts where there is a high subjective expectancy that they will occur. It is further predicted that particular kinds of alteration or breakdown of these familiar patterns in situations where their subjective probabilities of occurrence are close to unity should not affect the ability of subjects to recognise them on many occasions provided that the necessary proportions of critical identifying information may be derived from the display.

Where the subject happens to process a portion of a pattern information content which does contain an incongruity in relation to an expected pattern, he will perceive it as such, and exhibit a discrimination reaction to the altered pattern.

It is important to consider this general point in some detail. A question raised here is: Is it important to the experiment that the subject actually sees the display (i.e. in the sense that some analytical processing of the sensory data is involved), or that the subject thinks he sees the visual pattern? (i.e. he consciously experiences complete perception of the visual pattern). For the present discussion it is clearly necessary only that the subject is convinced he experiences perception of a particular pattern, whether it involves any analysis, however limited, of the real sensory pattern or not. However, it is clearly crucial to the validity of the proposed investigation that the subject should not simply guess the occurrence of given patterns, there being no overt or covert perception involved. There are a number of methods of controlling for this kind of contamination, such as, for example, the use of a two-stage pattern identification requirement, the use of catch trials, the use of particular verbal instructions, and the use of large sets of possible response alternatives. These methods will be outlined in the reports of the particular experiments.

2.8 An important notion emerging from the theoretical argument is as follows:-

Let the information content of a pattern be conceptually represented by a Venn diagram, the area of the circle representing the total information content of the pattern. Let P_1 be an overlearned pattern, and P_2 be a similar pattern such that P_1 and P_2 share a high proportion of common information content, as represented by Fig. 4 :-

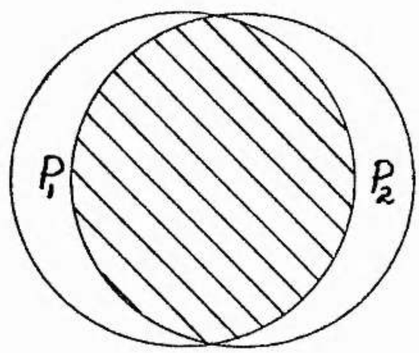

Fig. 4

If the subject in a recognition situation processes only a proportion of the sensory pattern information coming from the shared portion, then he will not exhibit any discrimination response between the two patterns. Further he will consciously experience complete perception of the pattern expected (P_1, say), as memory information complements the partially processed sensory information. This memory information contains that portion which is unique to the particular expected pattern.

2.9 A schematic flow chart showing the information flow dynamics of the pattern recognition component of the cognitive system according to the present model is given in Appendix I .

An important part of the research to be reported in the following chapters is the use of computer simulation techniques, incorporating the theoretical ideas outlined previously, to replicate the experimental work.

CHAPTER III

3.1 The previous chapters have described the background and development of the theoretical approach of the present research. This chapter describes an experiment which directly tests a fundamental hypothesis derived from the theory.

3.2 From the theoretical arguments of the present approach, the following specific hypothesis can be formulated (see p. 57):-

When the cognitive system of a human subject is not involved in any internalised cognitive information processing, in order to maintain the activity level of the system the available capacity of the system will be primarily dedicated to the analysis and processing of a greater proportion of real visual sensory input, whether or not it emanates from familiar patterns, than when the subject is engaged in internalised thought processes.

Conversely, when the subject is primarily engaged in internalised cognitive processing, less capacity is available for the analysis of real visual sensory input, and the amount of this analysis should be reduced accordingly.

In more general terms, if the present theoretical notions are correct, it should be the case that, when a subject is engaged in thought, he will elect to allocate less of his cognitive processing capacity to the analysis of available real visual sensory input from his environment than when he is not engaged in thought.

3.3 Experiments by Gould and his co-workers (Gould and Schaffer, 1965, 1967; Gould, 1967; Gould and Dill, 1969; Gould and Peeples, 1970) consider patterns of eye fixations as a "direct reflection of cognitive processing." (Loftus, 1972, p.527). For example, Gould and Peeples assume that refixation of a particular visual pattern indicates the "need to obtain more information about it" (1970, p.51). Loftus states that this research, together with analagous reaction-time research (e.g. Smith and Nielson, 1970; Tversky, 1969) "suggests that eye fixation patterns may be profitably regarded as an observable basis for inferring internal processing of visual information." (Loftus, 1972, p.528).

Therefore, from the premises of the present theory, subjects instructed verbally to "try not to think about anything" for a prescribed time period should exhibit significantly more gross eye movement activity than in an otherwise identical condition in which they are instructed to carry out an internalised mental task, even though this mental task should not nominally interfere with normal perception, as it involves no reference to, or utilisation of, real visual sensory input.

3.4 Method

i) Apparatus: The apparatus consisted of a Kipp and Zonen, Model BD8, flat bed recorder. Eye movement activity was recorded by placement of two electrodes adjacent to the left eye, one electrode at the left hand corner of the eye, and one just above the pupil at the mid point of the eye. These electrodes recorded the ocular muscular activity associated with eye movement. The experimental room was large with sizeable windows through which the subject could view the external scenery.

ii) <u>Subjects</u>: The subjects were eight undergraduate or postgraduate university students with normal corrected vision and no optical defects. Four subjects were male and four female. All subjects were unpaid volunteers, and had no prior knowledge as to the purpose of the experiment.

iii) <u>Procedure</u>: Subjects were seated comfortably in a chair in the experimental room, facing in the general direction of the windows. They were then wired up for recording of eye movements, their overall head movements not being restricted in any way. Subjects were told that the testing session was part of some work preliminary to a main study, and that their eye movements were being recorded simply as an operational reliability test of the recording apparatus, which was to be used extensively in a later experiment.

The purpose of this was to structure the demand characteristics of the experimental situation (Neisser, 1967) in such a way as to minimise emphasis on the real experimental interest in the amount of eye movement activity. The aim was to convince the subjects that they were not even participating in an actual experiment in the usual sense, their role being purely the preliminary one of operationally testing the apparatus.

Subjects were then asked to relax, the apparatus was switched on and the recording equipment checked. During this period subjects were instructed to blink and to move their eyes in various directions so that artifacts could be extracted from the later analysis of the data.

Standardised instructions to the subjects were as follows:-

Condition A: 'Although this might seem unusual, I want you, when I give the word, to try as hard as you possibly can not to think about anything for a short time, until I tell you to stop. The time period for this task will be two minutes.'

Condition B: 'I am going to tell you a three figure number, selected at random. When you hear this number, I want you to start counting silently to yourself, and as quickly as you can, backwards by threes. That is, subtract three from the number I give you, then three from that total and so on. You will continue to do this task until I tell you to stop - this period will be two minutes. I want you then to tell me the number you have arrived at. I have a fairly accurate estimate of where you should have got to, so try and concentrate hard on correctly keeping track of the numbers.'

Half the subjects were tested with condition A first, and half with condition B. The experiment was repeated for each subject, with the initial orders of the testing conditions reversed. On completion of the testing session, subjects were interviewed in order to check on any demand characteristics which may have enhanced or confounded the predicted results.

iv) Results: The paper tape pen record of eye movements under conditions A and B were compared for the two experimental treatments for each subject. Because of the relatively basic nature of the apparatus and the record, differences between amounts of eye movement in the two conditions were estimated by gross visual comparison of the adjacent raw data recordings for conditions A and B. The differences obtained were quite clear. However, a second independent observer, who had no knowledge of the aims of the experiment nor of any previous ratings of the data, also similarly rated the eye movement activity records for differences between the two conditions. Both observers' ratings correlated perfectly.

The results are shown in table I.

The results very strongly support the experimental hypothesis, only one result being contrary to that predicted, and three showing no obvious detectable difference. If the tied instances (i.e. no difference in eye movement activity between conditions A and B), are ignored, then the experimental hypothesis is supported in 12 out of 13 cases, i.e. 92% of occasions. No subject exhibited results contrary to those predicted on both test and re-test, all subjects producing at least one clear response pattern in the predicted direction.

The post experimental interviews indicated that no subjects ascertained the true purpose of the experiment, and none consciously attempted to generate particular eye movement patterns according to any subjective assessment of the demand characteristics of the testing situation.

3.5. Discussion.

Although methodologically and technically straight forward, the experiment produced empirical data which confirm the basic predictions derived from the theoretical model. The consistency of the gross effect across subjects shows that, whatever the individual differences in information processing strategies, the broad notions of the model concerning the allocation of total processing capacity appear to be supported.

The results of the present experiment are further supported by data obtained in another experimental context using far more sophisticated eye-movement recording apparatus.

TABLE I

		order of testing			
Subject No.	Sex	A → B		B → A	
1	M	+	2	+	1
2	M	+	2	+	2
3	M	*	1	+	2
4	M	+	1	+	2
5	F	+	1	*	2
6	F	+	1	-	2
7	F	*	2	+	1
8	F	+	2	+	1

Key: + indicates significant difference in the predicted direction (i.e. more eye movement in condition A than B).

\- indicates significant difference in direction opposite to that predicted.

* indicates no observable difference between conditions A and B.

The numerals 1 or 2 in the 'order of testing' columns indicate the condition testing order for the experiment and its replication for each subject. e.g. subject no. 1 was first tested in the condition order B → A and the experiment was replicated using the testing order A → B.

In a series of experiments, Loftus (1972) investigated the extent to which recognition memory for pictures may be predicted by eye-movement patterns. In each experiment subjects were shown 180 pictures, and this was followed by a yes-no recognition test. It was found that "when pictures are viewed for a limited amount of time, memory performance is a positive function of the number of fixations on the picture", and that "with number of fixations held constant, performance is independent of exposure time" (Loftus, 1972, p.525).

Eye movements in Loftus' experiments were recorded using a modified Mackworth stand camera (Mackworth, 1967), a device utilising a corneal reflection technique and videotape recording facilities. Full descriptions of the apparatus and the techniques of data analysis employed are provided by Loftus (1972). Loftus' experiments are the first to systematically relate eye movement patterns to subsequent memory for the viewed material.

Earlier, experiments by Freund (1971) and Szewczuk (1970) compared recognition memory for pictures viewed normally and during simultaneous performance of a distracting cognitive task. Freund found that recognition performance was significantly worse for pictures viewed while performing a distracting mental task, viz. counting backward by threes, than for pictures viewed normally. The viewing time of 7 secs. per picture was the same in each condition.

Loftus investigated this situation, but in addition recorded eye movement activity. The important finding with regard to the present experiment was that in the viewing condition involving the concurrent task of counting backwards by threes, it was found that there was "about a 40% reduction" in the fixation rate compared to the normal viewing condition.

In Loftus' experiments, subjects were required to learn visual material presented to them, and in certain instances received financial reward for correct responses. Consequently, they can be assumed to have devoted their entire processing capacities to the optimal input and storage of the visual material. In the counting backwards situation, it is important to note that subjects were still attempting to learn the visual material, but the utilisation of a substantial amount of processing capacity in the performance of the internalised task reduced the capacity available for the purposes of perception. This reduction in processing of the visual data was clearly reflected in the concurrent reduction in eye movements.

It is considered that these findings of Loftus confirm the present results, the validity of the gross data-analysis methods employed, and the theoretical assumptions from which the experiment was derived.

3.6 Conclusions.

1) When specifically instructed not to engage in internalised cognitive processing, the perceiver consciously elects to utilise his processing capacity by dedicating it entirely to the analysis of his visual sensory environment.

2) When engaged in the performance of an internalised cognitive task, the perceiver elects to make available the necessary processing capacity to perform this task by reducing the amount of information processing connected with the analysis of real visual sensory input.

It is emphasised that these conclusions are general rules with regard to the fundamental distribution of proportions of overall information processing capacity, and therefore are not affected either by individual differences in the limit of this capacity, or by inter- or intra-individual differences in specific information-processing strategies.

NOTE During the development of the experimental procedure to be reported in the next two chapters, several extensive pilot studies were carried out. For example, a special computer program, written in FORTRAN IV using an IBM 360 computer, was evolved. This highly flexible program generated dot patterns within a 100 x 100 matrix according to pre-selected constraints imposed by the operator. Patterns composed of a particular number of dots, but of otherwise entirely random configuration could be generated. Also, prescribed geometric patterns, such as triangles, squares, trapeziums, etc., could be embedded in the matrix. These embedded figures could then be partially masked using a selected amount of random visual noise, or they could be randomly or selectively fragmented according to specific criteria. These patterns, which were printed out on paper, were then recorded onto video tape and presented to subjects on a television screen. In a dual-task situation, subjects had to perform a Posner (1962) information-reduction task (see p. 54), while simultaneously identifying the patterns, which were presented in complete, noisy or fragmented form. Because the Posner task required regular vocalisation of the classification responses, non-verbal pattern-recognition responses were made using a specially constructed item of apparatus incorporating a slowly moving paper tape. The subject's writing hand was strapped in place, and his pattern-identification responses were in the form of drawings of the pattern on the paper tape. Subjects could easily do this accurately, without averting their gaze from the screen. Although precise arbitary quantification could be achieved using these methods, tests showed that insufficient visual pattern complexity could be achieved on the screen to provide meaningfully structured visual stimuli which presented identification problems to subjects - even in the dual-task situation. Further, considerable technical problems associated with stimulus synchrony were encountered. It also became clear that the arbitary quantification of the highly artificial patterns was of limited real usefulness, and bore little meaningful relationship, to the problems of perception of real overlearned complex patterns in the situations to which the research was addressed. Similar problems resulted from other pilot investigations using continuous, moving, input, in which the camera travelled over a fixed path. However, although they were difficult and time-consuming, the experimental and technical data resulting from the carrying out of pilot studies of this nature were of valuable assistance in the formulation of the definitive research concepts and procedures reported in the following chapters.

CHAPTER IV

4.1 A primary concern of the present thesis is the recognition of overlearned, anticipated complex visual patterns in situations where the perceiver is able to devote only part of his conscious attention to the performance of this task.

Pictures of real perceptual environments typically encountered by subjects, in the form of still photographs, film, or video recordings represent extremely complex visual patterns. These patterns are far more complex than the simple letters, numbers, geometric patterns or line drawings which are generally employed in the vast majority of laboratory investigations of human perception, memory and pattern recognition. It is considered that the possibility must be acknowledged that subjects in experiments involving such artificial stimulus situations, which the subject might never have encountered prior to the particular experiment, may develop novel forms of information processing strategies which are specific and referent only to these experimental situations. These strategies may bear no meaningful relationship to the way in which subjects perceive and remember in their normal perceptual information environments.

The use of photographic pictorial stimuli involves visual material which is extremely complex and, while still retaining some degree of artificiality, is at least arguably closer to the nature of the subject's perception of the real world than the visually simple stimulus material typically employed. Certainly, normal subjects have, without exception, experienced very frequent exposure to photographs from childhood. Thus, even if the cognitive processing strategies involved in complex picture perception are qualitatively different from those employed in perception of the real environment, as Gibson (1966, Ch. 11) has argued, the massive amount of exposure to pictures experienced by normal subjects ensures that well practised, developed and utilised picture processing strategies are in the subjects' repertoires. They are not, therefore, artifacts specific to the experimental situation; the "correspondences between surrogates and what they stand for" (ibid, p.235) have been well learned.

4.2 A further factor in favour of the utilisation of picture stimuli in the present context is the extreme ease with which pictures can be learned, as evidenced by the high levels of recognition performance achieved by subjects in picture memory experiments, after only very brief, single exposures to the pictures to be memorised. This empirical evidence indicates that pictures can be readily and rapidly overlearned if the exposure times are increased. This increase allows a greater number of eye fixations upon, and consequently a greater amount of information to be extracted from a stimulus picture by the perceiver (Gibson, 1966; Loftus, 1972).

In a series of experiments seeking the limits of picture memory, Standing (1973) has extensively investigated the power of picture memory, following up earlier studies by Nickerson (1965, 1968), Shepard (1967), and Standing, Conezio and Haber (1970). In one experimental condition, subjects were required to learn 10,000 'normal' pictures. As Standing points out, no simple metric exists for the specification of such pictorial stimuli. However, he states that the pictures used "may be categorised as resembling a highly variegated collection of competent snapshots" (ibid, p.208).

The 10,000 pictures to be learned were presented to subjects once only at an exposure time of 5 seconds, with an interstimulus interval of 600 ms. With the necessary rest periods, only 2,000 slides per day could be shown to the subjects. An average retention interval of two days was obtained by administering the recognition test immediately after the fifth daily learning session. This test consisted of 160 trials, in which two picture stimuli were presented side by side. One of these had been randomly selected from the learning set, and then randomly allocated to the left or right hand position. The other slide was selected from the total pool of 'normal' slides, but was one not previously presented to the subject. The subject wrote down an 'L' or an 'R' on each trial to indicate whether the left or right-hand picture looked the most familiar to him.

On the basis of these results, an estimate of the number of items retained in memory was calculated, making the usual guessing correction. It was estimated that 6,600 pictures were retained in memory. Standing concluded that, for pictures, "there is no upper bound to memory capacity; per cent retention gradually declines, but the absolute number of items retained always increases as the learning set is made progressively larger" (ibid. p.210). At the other extreme, recognition performance with small sets of 20 and 40 pictures, with equal numbers of recognition test trials, was almost perfect after a retention interval of two days. Performance on a 100 trial recognition test administered immediately after viewing 1,000 pictures was extremely good, subjects scoring a mean of 99.6 correct (median 100). This corresponds to a retention of 992 items.

4.3 In his paper, Standing notes that "apparently the only clear case of truly poor picture memory performance in the literature is that shown by Goldstein and Chance (1970) who carefully constructed extremely confusable items" (ibid. p.219). These investigators consider that previous studies (i.e. prior to 1970) of recognition memory for heterogeneous picture stimuli which suggest an unusually large storage and retrieval capacity have, in fact, overestimated this capacity. Goldstein and Chance argue that "in order to speak logically about 'accuracy' or 'correctness' in the results of these investigations, in contrast to those of studies of verbal learning, it must be assumed that the correct recognition responses made by these S's were to the particular, discrete picture, and not to the class membership of the stimulus. In other words, it must be assumed that S reacted to a previously seen stimulus as though it was in totality the identical stimulus shown to him earlier. Furthermore, it must be assumed that if the stimulus had been modified - even by a small change within the picture - between the first and second presentations, S could detect that stimulus and would react by reporting that the stimulus was not the one shown before" (ibid. p.327).

Goldstein and Chance put forward the proposition that, because the photographic samples typically employed in earlier studies are heterogeneous, the accuracy scores could be inflated estimates of picture recognition memory. An item could, they maintain, be recognised on the basis of its class membership rather than as a unique stimulus memorised on a previous occasion. Thus, what is stored in memory in such experiments is not detailed information about a particular stimulus, but a general concept, and with heterogeneous pictures this information may well be all that is required for recognition. Consequently, partially learned stimuli could be 'recognised' correctly, thereby increasing the 'accuracy' scores.

To test this notion, Goldstein and Chance investigated picture, or pattern, memory with sets of homogeneous stimuli. All the homogeneous stimuli within a recognition series came from the same psychological class, with interstimulus differences kept as small as possible without making any two stimuli perceptually indiscriminable when viewed simultaneously. The three classes of homogeneous stimuli used were complex snow crystal patterns, ink blots, and photographs of faces. Separate groups of subjects were shown 14 stimuli from each class for 2-3 sec, separated by a 5 to 8 sec. interstimulus interval. Recognition memory was measured either immediately, or 48 hours after presentation of the learning set. 84 randomly ordered stimuli were presented for 5 sec. each, this set containing the 14 stimuli previously seen. All the pictures in the recognition test set were of the same psychological class.

It was found that, in the immediate recognition test condition, faces were best recognised (77% correct for female subjects; 66% correct for males), followed by ink blots and snow crystals. However, the overall decrement in the delayed condition was only 9%, which is extremely small considering the single short stimulus exposure duration, and the homogeneity of the stimuli. Further, this decrement was almost entirely accounted for by recognition errors in respect of ink blot and snow crystal stimuli. Memory for faces was hardly affected by the 48 hour delay. Goldstein and Chance attribute the significantly better performance of subjects with respect to the faces stimuli to the greater familiarity and meaningfulness of faces as stimulus patterns, and the resultant greater interest of subjects in such patterns.

Overall, the results of these experiments do show significantly poorer picture memory performance than previous studies using heterogeneous picture stimuli. However, in spite of this, Goldstein and Chance state that their findings are still impressive demonstrations of the effectiveness of picture memory, and that "recognition performance of such high levels in the presence of essentially meaningless stimuli following a single brief exposure is intuitively surprising" (ibid. p.241).

4.4 In an experiment designed to overcome such methodological objections as those raised by Goldstein and Chance, Standing (1973) devised a recognition test in which 2, 4, 8, 16 or 32 alternatives were presented sequentially, rather than simultaneously, for 2 sec. each to the subject. The subject's task on each trial was to choose the picture he had previously seen for 2 sec. The larger number of sequentially presented alternatives "made the task more difficult and proportionately closer to the recall type of task" (ibid. p.213).

On the basis of the results of this experiment, Standing estimated that approximately 92% of items from a learning set of 100 stimulus pictures were retained in memory. This is a striking outcome, and together with the results from the 10,000 picture experiment described earlier, these findings do strongly suggest that, whether or not the capacity for picture memory is somewhat overestimated in the literature, memory for complex pictures is extraordinarily good.

4.5 To summarise, from the preceding discussion, the following conclusions can be drawn:-

1) Recognition memory for complex pictures is extremely good, even with very short single exposures to the set of pictures to be learned and long intervals between the presentation of the learning stimuli and the recognition test.

2) When the complex pictures used share a high degree of homogeneity, recognition memory performance is poorer than in the case of heterogeneous stimuli. It appears that this decrement is greater with meaningless, unfamiliar stimuli which are novel to the subject. In the case of homogeneous, familiar meaningful stimuli, such as faces, performance is not as poor as with homogeneous meaningless pictures. However, even when the sets of pictures are homogeneous, performance is still strikingly good.

These conclusions suggest that normal photographs provide complex visual information patterns which are likely to be readily, and rapidly overlearned by means of repeated, relatively long exposures to subjects. Subjects are able to achieve extremely high levels of performance with exposures of 1-2 sec. Thus, an exposure time of, say, 15 sec. should ensure maximum processing of the picture information. The evidence further indicates that subjects should readily be able to learn a series of small homogeneous sets of pictures, each of these sets representing a different stimulus category, and consisting of familiar, meaningful pictures.

4.6 On these premises a new form of picture recognition test is proposed, involving a two-stage identification process on each trial. The subject is required to identify a stimulus picture in two ways. He must (a) identify the stimulus category;

and (b) make an identification response with regard to the specific picture presented.

The use of such a procedure has a number of advantages from the standpoint of the present theory, and provides a much more sensitive measure of recognition performance than the typical two-choice, or heterogeneous multiple alternative procedures usually employed in picture memory studies. Differences in recognition performance may be measured in terms of both identification of the particular stimulus category, and identification of the specific picture within that category, thus providing two indices of performance.

Consider the following experimental picture memory situations:-

Subjects are required to overlearn a number of pictures. These pictures consist of a relatively small set of different, or heterogeneous, stimulus categories, each category being represented by a small number of homogeneous pictures within that category. Recognition performance is then tested by sequentially showing the subject brief exposures of a numerically larger set of pictures containing all the previously overlearned pictures, and consisting of the same heterogeneous set of stimulus categories. However, the number of homogeneous pictures within each category is increased. The subjects' task on each trial is to name both the stimulus category and to state whether or not the specific picture was one of those previously presented in the learning set. In this situation, it is hypothesised that subjects should make few, if any, errors in relation to identification of the stimulus category, but a small proportion of errors in relation to the identification of specific pictures within each homogeneous set.

Consider now the situation in which, during each trial in the 2-stage recognition test, the subject is simultaneously attempting to perform an internalised cognitive task involving no nominal visual distractions. According to the present theory, under these conditions only part of the subject's available cognitive processing capacity will therefore be able to be dedicated to the processing of the visual sensory information input. Because the picture stimuli presented in the learning set are overlearned, i.e. able to be well specified from information held in memory, and because the heterogeneous set of possible stimulus categories is known and expected by the subject, he should be able, in the dual-task situation, to process at least sufficient real visual sensory information input to identify correctly the stimulus category. His conscious perceptual experience in relation to the picture presented is completed by the utilisation of memory information by means of the imagery system. In this way the subject should consciously experience perception of one of the relevant overlearned expected visual information patterns within that category.

It is hypothesised that the subject should, in all instances, be able to process sufficient real sensory information to identify unequivocally the stimulus category, but he should make a considerable number of errors in relation to the identification of specific pictures. Clearly, these latter types of errors should occur when the subject processes a portion of the real visual sensory information pattern which is not different from the corresponding information characteristics of the overlearned expected pattern. However, if the differences between pictures in the homogeneous set are small, the probability that the subject will process a portion of the visual information which is referent to differences between the actual and overlearned patterns, is low. If part of the real sensory information processed on a trial is different to the corresponding portion held in memory, then the subject will correctly classify the picture as one not presented in the learning set.

4.7 A series of studies have attempted to relate 'vividness' of visual imagery, as measured by a questionnaire technique, to performance on picture memory tasks. These experiments have been carried out by Sheehan (1966a, 1966b, 1967b, 1972; Sheehan and Neisser, 1969) and the questionnaire employed was a shortened form of the 150-item Betts Questionnaire Upon Mental Imagery (Betts, 1909). Sheehan's briefer version of the Betts questionnaire requires vividness ratings along a 7-point scale for 35 items, consisting of 5 items for each of seven sensory modalities. (Sheehan, 1967a). The scores on the shortened form of the questionnaire correlated very highly ($r = 0.92$) with total scores on the 150-item scale.

On the basis of this questionnaire, subjects were classified as high or low imagers. The results of the studies attempting to show that subjects rated as vivid or high imagers on the Betts questionnaire perform better on picture memory tasks than those subjects rated as low imagers, have, on the whole, proven either inconclusive or negative, leading Neisser (1970) to conclude that questionnaire imagery ratings have little predictive value in relation to picture memory performance.

4.8 Marks (1973) challenges this conclusion for two main reasons. Firstly, using Sheehan and Neisser's (1969) study as a typical example, he notes that vividness ratings on each trial were obtained after recall. However, there is evidence (Marks, 1972) that this "rating-after-recall paradigm provides an artifactual basis for an accuracy-vividness relationship. In this paradigm the subject can use his recall performance as a cue for the value of the vividness rating. If ratings are obtained prior to recall, the within-subjects relationship between accuracy and vividness disappears" (Marks, 1973, p.17).

Secondly, Marks points out that the shortened form of the Betts questionnaire is referent to seven sensory modalities. Although Betts (1909) reported a moderately high correlation between ratings for different modalities, Sheehan and Neisser's (1969) experimental task involved visual stimuli only. Consequently, argues Marks, ratings of visual images alone would have been a more relevant basis on which to categorise and select subjects as 'high' and 'low' imagers. Further, Marks claims that it is reasonable to suppose that vividness of imagery will be related to the subjective level of interest, meaningfulness, and affect evoked by the stimulus which is imaged. It is probable that geometric designs, as used by Sheehan and Neisser, have low values along these variables. Thus, for these stimuli recall differences between high and low imagers would be less marked than differences in accuracy that might be obtained when other kinds of stimuli are used. (It should be noted that this argument exactly parallels that employed by Goldstein and Chance (1970) to account for poor recall performance of geometric snow flake, and ink blot patterns (see p. 80)).

4.9 Marks (1973) describes a series of experiments using a new 16-item questionnaire referent to the visual modality only, the Vividness of Visual Imagery Questionnaire (VVIQ). This test has a test-retest reliability coefficient of 0.74 (n = 68), and a split-half reliability coefficient of 0.85 (n = 150). The image summoned for each item is rated on the 5 point vividness scale shown in table 2, once with the eyes open and once with the eyes closed.

TABLE II

The rating scale used in the Vividness of Visual Imagery Questionnaire.

Rating	Description
1	'Perfectly clear and as vivid as normal vision'
2	'Clear and reasonably vivid'
3	'Moderately clear and vivid'
4	'Vague and dim'
5	'No image at all, you only "know" that you are thinking of the object'

Subjects were selected as either 'good' or 'poor' visualisers, and on this basis divided into two experimental groups. In the experiments, stimuli consisting of coloured photographs of scenes, or groups of unrelated objects were presented to the subjects. On each trial, after a 20 sec. delay, during which a subtraction task was performed to prevent verbal rehearsal, recall was tested using a multiple-choice questioning procedure, in which subjects were asked to describe particular details of the stimulus picture shown on that trial. (e.g. "What was directly below the suitcase: bicycle, candle, or books?").

In all three experiments performed, Marks reports that "verbal reports of visual image vividness were found to be reliable predictors of accuracy in the recall of information contained in pictures ... Image vividness, these data suggest, facilitates accurate recall" (ibid. p.23). This conclusion contradicts the negative conclusion reached by Neisser (1970).

4.10 In the present context, therefore, the VVIQ administered prior to testing picture memory performance, appears to be a suitable instrument by which to obtain an index of subjects' vividness of visual imagery which can be related to picture memory performance.

Marks' studies showed that 'high' imagers, as classified by the VVIQ, perform better on picture memory tasks than do 'low' imagers. However, in the dual-task condition, the situation is rather different. If it is assumed that subjects who are 'high' imagers possess an imagery system which is functionally more efficient than 'low' imagers, it seems plausible to argue that an efficient imagery system would thus be likely to contribute more information to perceptual experience in the divided attention context, thereby freeing additional capacity for internalised cognitive processing. In other words, more efficient information processing in the dual-task situation is likely to be obtained by maximal utilisation of the capabilities of the highly effective imagery system. Thus, more of the total composite sensory-memory information content of perceptual experience of overlearned visual information patterns will be provided by the imagery system of a 'high' imager than a 'low' imager.

On the basis of this argument, it can be hypothesised that 'high' imagers are likely to make a greater number of recognition errors in the dual-task condition, because less real visual sensory information is being analysed and processed. Consequently, alterations in the real sensory information array should be less likely to be detected. Conversely, in the recognition testing situation not involving the simultaneous performance of an internalised cognitive task, the evidence suggests that 'high' imagers should perform better than 'low' imagers.

4.11 The use of large numbers of trials in testing recognition performance in the dual-task situation requires the selection of a suitable internalised cognitive task. It was necessary that the task chosen meet the following specifications:-

i) It should not involve any visual distractions, thus ruling out, for example, any kind of mental problem solving task requiring visual sensory input, or the use of pencil and paper. The subject should be able to solve the problem without averting his gaze from the screen onto which the stimulus slides are projected.

ii) There should be no temporal regularity in the pattern of response required from the subject. Such tasks, (e.g. the information-reduction numerical classification tasks developed by Posner (1962)), typically present the subject with a series of auditory inputs, e.g. numbers, at a regular pace, and the subject must respond during the fixed time interval prior to the presentation of the next input. This fixed temporal regularity enables the subject to programme his attention switching, allowing optimal time sharing between the tasks, thereby minimising perceptual-cognitive interference i.e. the subject, knowing how much time he has on each trial, can proceed with one task, and then devote all his capacity to the other before the end of the time interval. (A further problem with the Posner tasks is that some of the classifications are sufficiently difficult to require the constant provision of visual referents, contravening the requirement of (i), above).

iii) The task should be sufficiently difficult to require maximum utilisation of the subject's processing capacities, but it should not be seen by the subject as impossible, thereby causing him to abandon it as hopeless, and devote all his attention to the performance of the picture memory task.

iv) The task should be sufficiently variable from trial to trial to eliminate repetition of closely similar problems, causing a practice effect which would make the task progressively easier for the subject over an extended number of trials. Such an effect would free additional capacity which could increasingly facilitate performance on the picture memory task.

v) The task should require as far as possible a reasonably continuous stream of information processing in order to proceed towards a solution, rather than a discrete series of specific stages. At the ends of such stages the subject could explicitly switch all attention to the memory task, then return to the problem and proceed easily from the memory marker provided by the previous discrete stage.

vi) The task requires auditory input to the subject, and verbal response.

vii) The time taken to solve the problem should be significantly greater than the exposure duration of the stimulus picture, to enable temporal randomisation of the presentation of the stimulus picture. This prevents subjects anticipating the occurrence of the stimulus picture and programming their attention switching accordingly.

In view of the above considerations the task chosen was that of mental arithmetic as it appeared to meet all the necessary requirements. Specifically, the problems were two-figure by two-figure multiplications, excluding all numbers ending in zero. (i.e. 10, 20, 30, 40 etc.). Thus typical problems were:- 64 x 67; 19 x 51; 27 x 38; 54 x 17 etc ...

Pilot studies showed that subjects found these problems difficult, but all possessed operational strategies which enabled the problems to be eventually solved.

4.12 It is emphasised that for the present purposes it is not necessary that the subject actually continues with each problem until a solution is achieved. It is necessary only that during the period in which the stimulus picture is presented, the subject is continuously processing information referent to the solution of the problem. The primary concern of the experiment is to ensure as far as possible that part of the subject's limited cognitive processing capacity is occupied during the time the stimulus picture is presented, so that only part of this capacity can be devoted to processing of the real visual sensory information input.

In order to investigate and test these theoretical notions the following experiment was carried out.

4.13 Method

(i) Apparatus

Sets of five similar black and white photographs were taken of 16 aspects of the local town and university environment likely to be highly familiar to the experimental subjects to be used in the experiment. The five homogeneous photographs forming each of the sixteen sets were obtained either by photographing the same basic scene from five slightly different angles, or the same scene from the one camera position but with dynamic features such as crowd and traffic patterns differing between each photograph. From the resulting pool of 80 transparencies, the best 10 sets of five were selected on the basis of photographic quality (e.g. clarity, contrast, brightness) and adequate perceptual discriminability between the five individual members of each set.*

To present the visual stimuli, a Kodak Carousel S slide projector, equipped with a solenoid operated shutter device manually operated by a micro switch was used. The duration of exposure of the slide was controlled by a variable timer wired into the circuit. The slides were projected onto a white screen in front of the seated subject, the centre of the projected picture being approximately at the subject's eye level. The screen was at a distance of approximately 2.6 metres from the subject's eyes.

A Ferrograph Vortexion tape recorder was used to record subject's verbal descriptions.

The experimental room was well sound-attenuated, but in order to mask any possible distracting extraneous noises a white noise generator emitted very low intensity

* Prints of these photographs are shown in Appendix III.

noise through a small loudspeaker for the duration of the testing session.

(ii) Subjects

14 undergraduate and postgraduate students of the University of St. Andrews (7 male, 7 female) were employed in the study. All had normal corrected vision and no optical defects. None of the subjects had any knowledge in relation to the purpose of the experiment.

(iii) Procedure

At the commencement of the session, subjects were comfortably seated in the experimental room and the VVIQ was administered. (The complete 16-item questionnaire is shown in AppendixII). Subjects completed the VVIQ at their own pace, alone in the experimental room. The experimenter left the room after explaining the VVIQ procedure to minimise any distraction, time-pressure or embarrassment of the subjects, none of whom had previously encountered a questionnaire of this type. In the instructions to the VVIQ subjects were directed to complete the whole 16 items, imaging with their eyes open, and secondly the entire 16 items imaging with their eyes closed. This procedure was adopted to minimise visual adaptation after effects resulting from alternating eyes-open, eyes-closed imagery.

On completion of the VVIQ, the experimenter returned to the room. A series of 20 stimulus slides, consisting of two homogeneous slides from each of the 10 heterogeneous stimulus categories was then shown to the subject. The two homogeneous slides from each category were presented consecutively so that subjects could be made aware of the sorts of differences they could expect between pictures within the homogeneous sets. The learning set of 20 slides was presented once for five seconds exposure per slide, then a second time, in the reverse order, again for five seconds exposure per slide, and, finally, a third time in the original order at an item exposure time of five seconds. Thus, each picture was seen by the subject for a total of 15 seconds, and the subject had three occasions on which to compare the slides of each pair. For the reasons outlined earlier (p. 77), it was considered that, in view of the power of picture memory empirically demonstrated in experiments using large numbers of stimuli and very short exposure durations, 15 seconds presentation time would be more than sufficient to ensure over-learning of the stimulus pictures. Further, the consecutive display of the two homogeneous pictures within each category ensured that subjects were well aware of the extent to which these pictures varied.

As an additional control to show that all the pictures in the learning set had been memorised, subjects were asked in the absence of any visual stimuli to free-recall and describe to the experimenter in detail all the slides they had been asked to memorise. This verbal description was tape recorded for later analysis of recall order and amount and nature of detail.

The following instructions were read to all subjects prior to the presentation of the learning set of pictures:

"You will now be shown a series of 20 photographs of places and things that will be very familiar to you. I want you to commit these pictures to memory, as you will be required to recognise them among sets of similar pictures later on. Although there are 20 pictures in all in this first series, there are only 10 basic scenes, so that you will see two similar pictures of the same scene for each of the 10 scenes. All the pictures are different - no two are the same. To enable you to make direct comparisons of the differences between the similar photographs, the two members of each pair will be presented one after the other. You will see the whole set through, with each picture exposed for 5 seconds. Then you will see the series again, in the reverse order, for 5 seconds per slide. Finally, you will see all the slides a third time for five seconds each in the original order. Remember to try as hard as you can to concentrate on memorising the pictures. Do you have any questions?"

For the recording of the verbal descriptions of the pictures, subjects were simply instructed to describe in any order they wished, and in their own words, all the pictures they had been asked to memorise.

After completion of recording of the subject's verbal description, and checking that the subject had verbally described all the sets of pictures presented, the recognition performance of the subject was tested in the following way:-

(A) Control group.

The entire set of 50 slides, which included the learning set, was then presented to the subject, with an exposure time of 1 second per picture, at an interstimulus interval of approximately 5 to 10 seconds.

This interval was dependent upon the response time of the subject. The task was not forced paced. Within the overall set of 50 slides, the 5 homogeneous photographs of each stimulus category were presented consecutively, with the 2 learned stimulus slides randomly ordered within each of these sets.

After each exposure the task of the subject was to (a) identify the stimulus category which the particular photograph represented; and (b) state whether or not he had seen that specific picture before, i.e. whether or not it was one previously memorised in the learning situation. Performance on each trial on these two indices was recorded by the experimenter.

Instructions to subjects in the control group were as follows:-

"You will now be shown a large number of pictures. Each picture will be presented for 1 second. All the photographs you are about to see are of the <u>same</u> ten basic scenes or objects shown to you earlier. However, this time there are <u>more</u> similar pictures of each scene in addition to the pair you have already memorised. All of the pictures you have memorised will be presented again <u>once only</u> in this larger sequence, and no two pictures in this bigger set are the same. Every picture is different in some way from every other.

After each picture has been shown, I want you, in your own time, to tell me two things about it. First I want you to identify the particular scene or object, and, secondly, I want you to tell me whether or not you have seen that specific picture of the scene or object before - that is, whether or not it is the same as a picture you have memorised earlier. You must make a definite decision; you cannot answer 'I don't know'. After I have recorded the results, we will go on to the next trial. I will read these instructions again as it is important that you understand the procedure exactly. Do you have any questions? We will work at your own pace, and if you want a short break, please tell me".

The 50 slides were then presented to the subject and the results recorded.

(B) Experimental group.

For this group, the testing procedure was essentially the same as for the control subjects, with the following important differences:

Prior to the presentation of each slide, the subject was given a mental arithmetic problem to solve. (see p. 91). Before testing with the pictures, the subject was given several practice trials on this internalised cognitive task alone. This was done so as to ensure that the subject had no special mathematical ability enabling him to solve such problems extremely rapidly. In the dual-task testing situation, at some random time during which the subject was concentrating upon attempting to solve the problem, while continuing to look at the screen, the picture was exposed for the one second interval. The timing of the presentation of the slide was randomised to reduce anticipation by the subject. The subject was allowed to continue with the problem for a period of up to 20 seconds. If he had not solved it in this period, the experimenter interrupted and asked for the information about the slide. This information was recorded as for the control group, together with the outcome of the subject's attempt to solve the mental arithmetic problem. The next problem was then given, and the next slide exposed, repeating the procedure for the 50 slides. At intermittent intervals, the experimenter verbally encouraged the subject to keep trying hard to solve the mental arithmetic problems, even though he might be having no success.

The instructions to subjects in the experimental group were as follows:-

"You will now be shown a large number of pictures. Each picture will appear on the screen for 1 second. All the photographs you are about to see are of the <u>same</u> ten basic scenes or objects shown to you earlier. However, this time there are <u>more</u> similar pictures of each scene in addition to the pair you have already memorised. All of the pictures you have memorised will be presented again <u>once only</u> in this larger sequence, and no two pictures in this bigger set are the same. Every picture is different in some way from every other.

After each picture has been shown, I will want you to tell me two things about it. First, I want you to identify the particular scene or object, and secondly, I want you to tell me whether or not you have seen that specific picture of the scene or object before - that is, whether or not it is the same as a picture you have memorised earlier. You must make a definite decision; you cannot answer 'I don't know'.

Now, before each picture is presented I am going to give you a mental arithmetic problem like the ones you have just practised. It will be a difficult, but not impossible problem and I want you always to try as hard as you possibly can to <u>attempt</u> to solve it, even though you may not get any of the answers. This is extremely important. The experiment requires that you try as hard as you can. If you get the answer, tell me, and then tell me about the pictures. After I have recorded the results we will go on to the next trial. As soon as I give you the problem, you must start looking at the screen where the slide will appear and continue to do this throughout the trial. The slide will be projected onto the screen at some random time after you have commenced solving the problem. If at any time you feel you want a rest break please tell me and we will stop for a short period.

I will read these instructions again as it is important that you understand the procedure exactly. Do you have any questions?"

In both experimental and control groups subjects were given a rest break after half the slides had been shown. Additional short breaks were given at the subject's request. Although for the experimental group particularly, the testing session was somewhat arduous, the experimenter attempted to maintain a relaxed minimum stress atmosphere in the testing room throughout the experiment.

At no point in the experiment were subjects given any feedback with respect to their picture memory performance. The reason for this was that subjects' responses to the identification of specific pictorial stimuli within a homogeneous set could be strongly influenced by a knowledge of results. For example, if a subject had responded in the affirmative to the identification of two specific pictures within a set and had been told that he was correct, this knowledge would ensure that his responses would be negative to the remaining pictures in the set, whether or not he was certain on the basis of visual information alone.

On completion of the experiment subjects were interviewed by the experimenter and invited to comment on any aspect of the experiment.

4.14 Results and Preliminary Discussion

(i) Picture Memory.

The recognition performance of subjects is shown in table III.

No subject in either group made any errors at all in the correct identification of the stimulus category. In the control condition performance across subjects was extremely consistent, although, as predicted, some errors were made with respect to the identification of specific pictures within each homogeneous set. (mean errors = 6.5; S.D. = 1.8). However, subjects scored a mean of 87% correct, a strikingly good result considering the difficulty of discrimination within each homogeneous set of pictures. This performance is somewhat better than that achieved by subjects in the memory for faces condition of the experiment of Goldstein and Chance, described earlier (p. 80), and probably reflects the lesser homogeneity across the entire set of pictures in the present experiment.

Performance across subjects in the experimental group was also consistent. However, for these subjects the

TABLE III

Group	Subject	E_1	E_2
Control	MM	0	5
	NB	0	7
	LO	0	7
	DL	0	6
	DR	0	4
	DM	0	10
	GP	0	8
	BS	0	5
	Mean/S.D.	0/0	6.5/1.8
Exptl.	PT	0	15
	IG	0	18
	JF	0	16
	BC	0	10
	GB	0	15
	MW	0	17
	Mean/S.D.	0/0	15.16/2.54

Key: E_1 number of errors in recognition of the stimulus category

E_2 number of errors in relation to identification of specific pictures.

mean number of errors in relation to the identification of specific pictures was over twice as great as for the control group. There was no significant difference at the 0.05 level between the unbiased estimates of the population variances of the experimental and control groups ($F = 0.478$; $V_1 = 7$, $V_2 = 5$). Thus, for this parameter, the variances of the two populations were homogeneous, and a normal 't' test could be used to test the significance of the difference between the sample means.

The difference between the mean number of specific picture errors (E_2 in table III) made by the experimental and control groups was found to be significant at the 0.002% level ($t = 6.9$, 12 degrees of freedom).

These results very strongly support the experimental hypotheses derived from the theory, i.e. that subjects in the dual-task condition would make more specific picture errors than those in the control condition who could dedicate all their cognitive processing capacities to performance of the recognition task. The E_2 error distributions of the two groups does not even overlap, just touching at one point. It seems apparent that the effect observed in this experiment is a very powerful one, and that the imposition of the simultaneous internalised cognitive task upon the picture recognition task has the empirical effect on performance specifically predicted by the present theory.

An extremely important result of the experiment is that, on the basis of picture memory performance with respect to the correct identification of the 10 heterogeneous stimulus categories alone (E_1), there was no difference whatsoever between the experimental and control groups, each group performing perfectly. It is only when the second index of performance (E_2) is utilised that the very great differences between the groups in picture memory performance become clearly apparent. Thus, in a dual-task situation such as that used in the present experiment, it is highly probable that no differences between experimental and control groups would be found if only heterogeneous stimuli were used. On the basis of this argument it would appear that subjects in the usual type of picture memory experiment need not devote their maximum cognitive processing capacity to the task in order to perform at the very high performance levels typically observed.

The lack of any errors by subjects of either group in identification of the heterogeneous categories is proof that subjects were always processing at least a sufficient proportion of the visual information array to correctly identify this aspect.

It is important to note that, even though subjects in the experimental group made a large number of errors in comparison to the control group, they still scored 69.68% correct responses.

(ii) Analysis of error patterns in picture memory performance

As stated earlier (p. 77), Standing (1973) has pointed out that there exists no straightforward objective method which may be employed to dimension the nature of a complex picture such as a normal photograph. Consequently, it is impossible, with the natural photographs used in the present experiment, to control precisely for equality of memory difficulty, either across the heterogeneous categories or within the homogeneous sets forming these categories. Therefore, it is to be expected that different categories will present varying degrees of difficulty to subjects.

Table IV shows, for experimental and control groups, the total percentage of errors made by all subjects with respect to the homogeneous pictures in each set, for each of the 10 stimulus categories.

TABLE IV

Stimulus category	1	2	3	4	5	6	7	8	9	10
% errors, Control group	20	10	0	5	17.5	20	12.5	15.0	32.5	7.5
% errors, Experimental group	33.3	16.6	6.6	13.3	50	53.3	20	36.6	40.0	23.3

Graphing the results shown in table IV shows very clearly that the error patterns for both groups across the 10 stimulus categories are extremely similar (Fig. 5). The error patterns covary closely ($r = 0.77$) illustrating that the <u>relative</u> difficulty of the homogeneous sets for each stimulus category remained virtually unaltered by the imposition of the internalised cognitive task. This is an important finding, as, if the effect of the simultaneous performance of the cognitive task was merely one of a generalised confusability across the heterogeneous categories, the particular error pattern of the control group would not have been almost exactly replicated by the experimental group. The fact that the correlation between these group error patterns is so high shows that the effect is one of a pure negative shift in performance level in respect of the experimental group, which

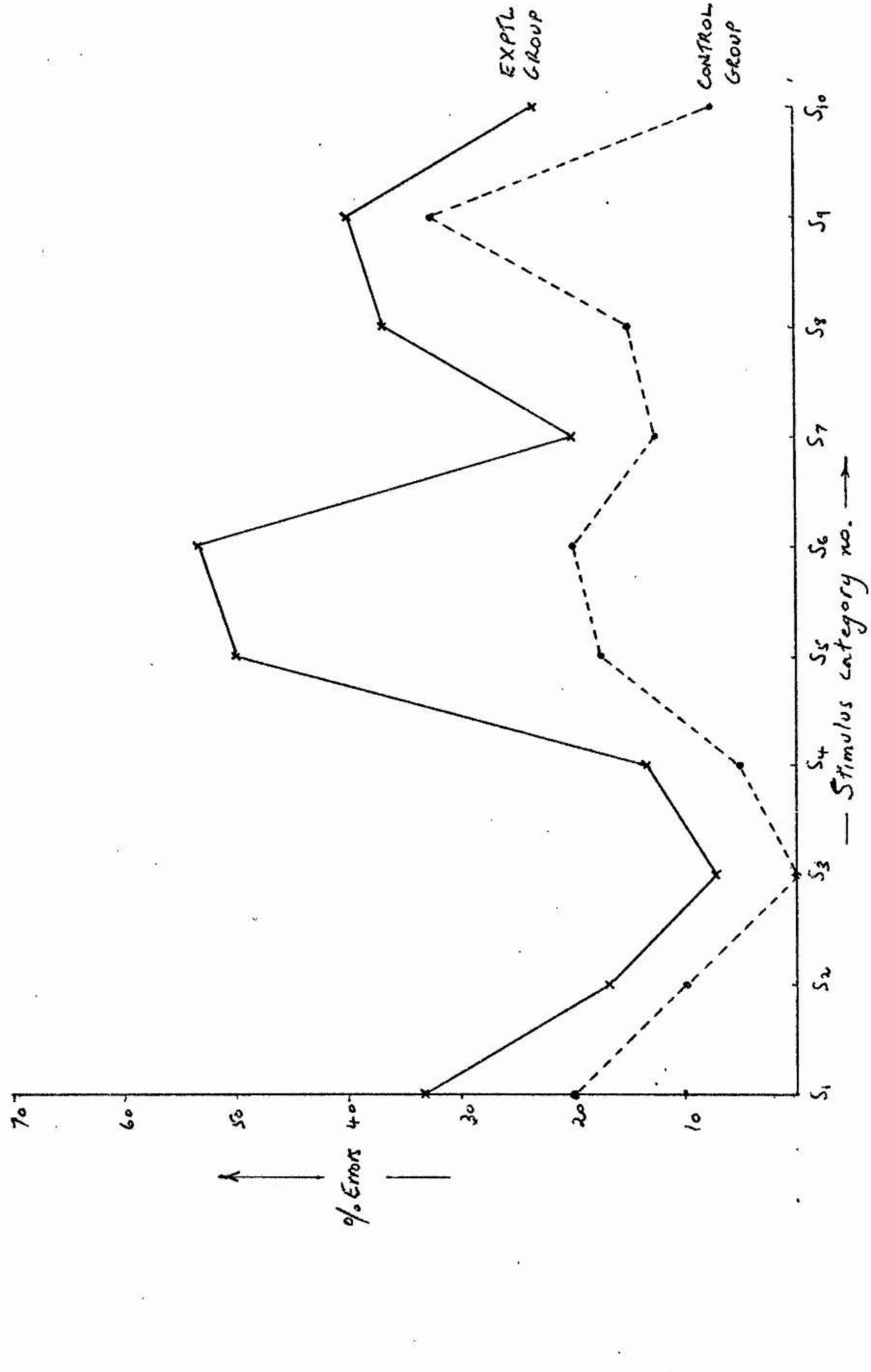
EXPTL GROUP
CONTROL GROUP
% Errors
70
60
50
40
30
20
10
S_1
S_2
S_3
S_4
S_5
S_6
S_7
S_8
S_9
S_{10}
Stimulus category no.

FIGURE 5.

retains the selectivity of the control group with respect to the memory difficulty of the various categories.

It appears that the cognitive processing capabilities and strategies of the subjects referent to the picture memory task remain qualitatively the same for the two groups. The effect of the second task appears to be essentially one of a reduction in the amount or power of this picture processing facility and not a fundamental change in its nature.

This empirical qualitative finding lends further strong support to the basic validity of the theoretical concepts and methodological strategies on which the experiment was based. The effect observed is congruent with a reduction in the amount of real visual sensory information which is being processed in the dual-task situation, the errors being a result of this. The nature of the processing is not changed, but the amount of real visual sensory information the system has to work with is reduced. Errors are a direct result of this reduced input of real sensory information in accordance with the theoretical arguments outlined previously (p. 84).

(iii) Order of free recall of the 10 stimulus categories in relation to errors on those categories.

Reference to the graphs shown in Fig. 5 shows that for both experimental and control groups stimulus categories S_6, S_5, S_9, S_8 and S_1 evoked the highest E_2 error rates. The stimulus categories being presented in the numerical order S_1 to S_{10} in both the learning and recognition test situations (except for one presentation in the learning situation of items in the order S_{10} to S_1).

It might be that there were more errors associated with these categories because they were less well, or less vividly, remembered. Prior to testing recognition performance, for both groups, subjects were asked to free-recall and describe verbally the pictures in the learning set. These descriptions were tape recorded. No subject failed to remember any of the stimulus categories, and virtually all accurately described the essential differences between the two homogeneous pictures shown in each stimulus category. This was clear evidence that all the pictures in the learning set had been well overlearned by all subjects. However, it is reasonable to argue that it is possible that those pictures and stimulus categories free-recalled first were the best remembered, and those recalled last were the least well remembered.

Because of the consistency of performance of subjects within each group, and the virtually identical error patterns of each group, (i.e. the rank order of stimulus categories in terms of the numbers of errors associated with them was the same for both groups), the total numbers of errors by <u>all</u> subjects on each category can be compared with a cumulative frequency index of free recall rank order for that category.

Thus, for each stimulus category we can determine the number of times it was free-recalled first by all subjects, the number of times it was recalled second, third, fourth and so on. Then, by multiplying the frequency by the rank in each cell, and summing across the ten ranks for each stimulus category a single weighted index of rank order for each category is obtained. Using this procedure, a category which was more often recalled earlier in the free recall sequence will have a numerically lower index than one generally recalled later. These indices can then be ranked and this rank order directly compared with rank order of total errors in each stimulus category.

Tables V and VI show this procedure.

TABLE V

Calculation of weighted rank index

		Rank										
		1	2	3	4	5	6	7	8	9	10	Weighted rank index (rank x frequency)
	S_1	6	1	0	2	3	1	0	1	0	0	45
	S_2	0	4	5	1	2	1	0	0	0	1	53
	S_3	3	2	3	1	0	1	2	1	0	1	58
	S_4	0	0	1	1	2	2	2	3	2	0	85
	S_5	0	0	0	2	2	0	3	0	5	2	105
Stimulus Category	S_6	1	2	0	1	0	1	2	1	3	4	104
	S_7	2	1	0	3	1	0	0	1	1	5	97
	S_8	1	1	1	1	2	4	1	3	0	0	75
	S_9	0	2	1	1	3	2	0	4	1	1	89
	S_{10}	1	1	3	2	0	2	4	0	1	0	69

The numbers in each cell show the frequency with which all subjects free-recalled the particular category at that particular rank. e.g. 6 subjects free-recalled category S_1 first.

TABLE VI

Rank index and errors for all stimulus categories

Categories	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Weighted rank index	45	53	58	85	105	104	97	75	89	69
Total errors on the category	18	9	2	6	22	24	11	17	25	10

Using Spearman's rank-order correlation coefficient it is found that the correlation between these rankings is $r_s = 0.51$. This correlation does not reach significance at the 0.05 level ($t = 1.68$, degrees of freedom = 8) (Hays, 1963, p.646). However, it does indicate that there was some positive tendency for fewer errors to be associated with categories described earlier in the free recall situation.

The rank-order correlation between order of presentation of the stimulus items and the rank order of recall over all subjects is $r_s = 0.46$, again not reaching significance at the 0.05 level ($t = 1.47$, degrees of freedom = 8). This indicates some slight tendency for items presented first to be free recalled earlier.

It is considered that, overall, the power of picture memory and the overlearning of the stimulus pictures, together with the fact that all were easily recalled verbally by the subjects is evidence that any potential order effects in recall were eliminated by the relative ease of the memory task.

(iv) Errors of recognition of the overlearned pictures

The number of errors made by subjects in relation to memory for the particular pictures in the learning set is shown in table VII.

TABLE VII

Errors with respect to the particular pictures memorised.

Group	Subject	errors Gross/w.r.t. pictures in the learning set (A)	Total errors (B)	A/B %
Control	MM	2	5	40
	NB	3	7	42.8
	LO	1	11	9.0
	DL	1	6	16.6
	DR	2	4	50.0
	DM	7	10	70.0
	GP	5	8	62.5
	BS	4	5	80.0
				Mean 46.36%
Exptl.	GB	4	15	26.6
	MW	6	17	35.2
	BC	1	10	10
	PT	3	15	20
	JF	3	16	18.7
	IG	8	18	44.4
				Mean 25.81%

For subjects in the control condition, errors of identification of the pictures in the learning set formed a mean of 46.36% of the total number of errors made by each subject. Note that the control subjects made far fewer errors overall than the experimental subjects. However, keeping this point in mind, close to 50% of the errors made by the control subjects were in relation to the identification of pictures memorised in the learning set. What errors that were made by the control group subjects seemingly occurred on a random basis in relation to whether the picture had been overlearned previously, although the total number of errors made on each category varied with the 'difficulty' of the category.

For the experimental group, the position is quite different. Although the mean number of E_2 errors made by the experimental group was over twice as great as that made by the control group, the mean proportion of these errors made with respect to the pictures overlearned prior to testing in the dual-task situation, was virtually only half as great as for the control group (= 25.8%). In other words, subjects in the experimental group made many more errors than those in the control group, but the proportion of these total errors which was due to incorrect identification of the pictures in the learning set was much smaller in the case of the experimental group. The difference between these mean percentages was significant at the 0.1 level on a two-tailed test, and close to significance at the 0.05 level ($t = 1.85$; 12 degrees of freedom).

This analysis shows clearly that, in general, subjects in the dual-task situation correctly identified the overlearned stimulus pictures on most occasions, but a mean of 74.19% of their errors in this situation consisted of responding that the stimulus picture shown was one they had previously overlearned, when in fact it was not. The nature of this finding is precisely that predicted by the theoretical arguments outlined previously (p. 84). Because of the high degree of homogeneity of the picture sets within stimulus categories, the probability of the subject in the dual-task situation processing a proportion of the sensory picture information different to the corresponding portion of the information held in memory regarding the overlearned picture, was low. Consequently, these subjects processed sufficient of the real visual sensory information to confirm an expected stimulus category, and consciously experienced perception of one of the relevant homogeneous pictures from the overlearned set, and identified it as such. Subjects in the dual task condition tended more often to 'see' the pictures presented as those they had overlearned and correspondingly made a greater proportion of inappropriate affirmative identifications.

It should be noted, however, that the grouping of the 5 homogeneous pictures within each category in the testing situation may well have decreased the subject's uncertainty with regard to the next picture to be presented. Thus, he need process even less real sensory information to confirm the presence of an expected pattern than in an experimental testing situation in which the presentation sequence of all pictures was randomised. Consequently, more processing capacity could be dedicated to performance of the internalised cognitive task, and a greater proportion of pictures would be perceived as those previously learned. Therefore, the randomisation of picture presentation could well decrease the effect observed here.

(v) The imagery data.

The imagery data obtained in the experiment present a complex and intriguing picture. The VVIQ scores for all subjects, together with errors in respect of identification of specific pictures (E_2), are shown in Table VIII.

TABLE VIII

VVIQ Scores for all subjects

Group	Subject	E_2	Total VVIQ Scores: Eyes open	Eyes closed	Total	Mean Rating
Control N = 8	MM	5	21	29	50	1.56
	NB	7	27	37	64	2.0
	LO	7	37	32	69	2.15
	DL	6	45	28	73	2.28
	DR	4	39	51	90	2.81
	DM	10	39	41	80	2.5
	GP	8	59	52	111	3.46
	BS	5	69	58	127	3.96
	Mean/SD	6.5/1.8	42/14.73	41/10.72	83/23.78	2.59/.74
Exptl. N = 6	PT	15	40	43	83	2.59
	IG	18	55	34	89	2.78
	JF	16	36	23	59	1.84
	BC	10	44	43	87	2.71
	GB	15	48	47	95	2.96
	MW	17	43	58	101	3.15
	Mean/SD	15.16/ 2.54	44.33/ 6.01	41.33/ 10.84	85.66/ 14.51	2.67/.41

In the present experiment, subjects were not separated 'a priori' into 'good' and 'poor' visualisers on the basis of the VVIQ, the VVIQ being administered at the experimental session to all subjects who volunteered for the experiment. However, conditions for administration of the VVIQ were extremely good, the subject being left alone in a sound-attentuated room to complete the questionnaire at his own pace, under no pressure from the experimenter. All the subjects were highly motivated, and it is considered that, if the VVIQ is a true index of imagery, then the circumstances of the experiment maximised the validity of the scores obtained. On the average, subjects took 20 to 25 minutes to complete the VVIQ. If the VVIQ is a sensitive measure of vividness of visual imagery, it should be expected that, overall, imagery scores should covary reasonably consistently with picture memory performance.

Reference to table VIII shows that for both groups there is no significant difference between the mean imagery scores for eyes open and eyes closed conditions, and that there are no significant differences between the mean VVIQ scores obtained for the experimental and control groups. In all instances the between-subjects variance of the VVIQ scores is considerable. For all subjects the correlation between total VVIQ scores for the eyes open and eyes closed imagery conditions was found to be only $r = 0.56$. It would therefore appear to be interesting to investigate the various relationships between E_2 errors and imagery scores obtained under the eyes open and eyes closed conditions, in addition to the total VVIQ score. (Marks (1973) provides no information on the above points, using only the mean item rating of the subject's responses over <u>all</u> VVIQ items. Separate mean ratings for 'eyes open' and 'eyes closed' conditions are not shown in his results).

Accordingly, the following results were obtained:-

(a) <u>Control group</u>.

Product-moment correlation between E_2 errors and:-

i) Total VVIQ score - $r = -0.004$

ii) Eyes open VVIQ score - $r = 0.00$

iii) Eyes closed VVIQ score - $r = -0.1$

These correlations are small and insignificant, indicating no apparent descriptive association between VVIQ scores and memory performance for the control group.

(b) Experimental group.

Product-moment correlation between E_2 errors and:-

i) Total VVIQ score - $r = 0.04$

ii) Eyes open VVIQ score - $r = 0.24$

iii) Eyes closed VVIQ score - $r = -0.09$

These correlations are also small and insignificant.

On the basis of these results, scores on the VVIQ appear to have no relation to picture memory performance in the present experiment. However, there is a plausible reason why this might not be so. The cognitive processing requirements of the picture learning and memory tasks employed may be sufficiently within the potential capabilities of all subjects so that they all perform well on these tasks. The index of performance provided by the picture memory task is not sensitive enough to discriminate between 'good' and 'poor' visualisers at this level of performance. Certainly, this appears to be true of the control group, where the mean number of E_2 errors is relatively small, all subjects performing very well.

In the dual-task situation, processing performance should be closer to the limits, and it is somewhat surprising, given the results achieved by Marks (1973), that no relationships between vividness of visual imagery and memory performance were apparent here.

Referring to table IV , it is observed that, based on the total number of errors for the particular stimulus category, certain stimulus categories were considerably more difficult than others with respect to the memory task. Consequently, if the preceeding argument is correct, and performance superiority of good visualisers only becomes apparent at higher levels of performance, let us consider relative performance on those categories only. The variance contributed by errors on the 'easier' categories could possibly be masking any covariance between high imagery and good picture memory performance.

Thus, referring to table IV, consider total errors on S_1, S_5, S_6, S_8 and S_9 only. Total errors on these categories for each subject are shown in table IX , together with the associated imagery data.

Product-moment correlations between E_2 error and imagery scores for these categories were as follows:-

(a) Control group

Correlation between E_2 errors and:-

(i) Total VVIQ score $r = -0.14$

(ii) Eyes open VVIQ score $r = 0.00$

(iii) Eyes closed VVIQ score $r = -0.3$

(b) Experimental group

Correlation between E_2 errors and:-

(i) Total VVIQ score $r = -0.28$

(ii) Eyes open VVIQ score $r = -0.45$

(iii) Eyes closed VVIQ score $r = -0.09$

In the case of the control group, the correlations remain generally small, supporting the argument that in the control condition the task is well within all subjects' performance capabilities, whatever may be their individual

TABLE IX

Imagery scores and errors on

'difficult' stimulus categories.

Group	Subject	E_2 errors	VVIQ scores: Eyes open	Eyes closed	Total
Control	MM	3	21	29	50
	NB	4	27	37	64
	LO	9	37	32	69
	DL	6	45	28	73
	DR	4	39	51	90
	DM	7	39	41	80
	GP	6	59	52	111
	BS	3	69	58	127
Exptl.	PT	12	40	43	83
	IG	10	55	34	89
	JF	12	36	23	59
	BC	9	44	43	87
	GB	12	48	47	95
	MW	11	43	58	101

differences in vividness of visual imagery. However, although small, two of the correlations are negative, indicating a very slight tendency for high imagers, or good visualisers, (i.e. with a low VVIQ score) to make errors in the control situation. This result suggests that the performance requirements of the task are so well within the capabilities of good visualisers that they perform it without devoting all their cognitive processing capacities to it, thereby making more errors for the reasons outlined earlier (p. 84).

For the experimental group the correlations are all negative, and that between E_2 errors and the eyes-closed VVIQ score is - 0.45, an absolute value considerably greater than for any correlation found in the case of the control group. These findings support the argument that the performance differences between 'high' and 'low' imagers become apparent only at the higher performance levels required by more difficult situations.

The most important aspect of these results is that the single relatively large correlation, and the negativity of all the correlations, for subjects in the dual-task situation offer firm empirical support for the hypothesis proposed in detail earlier (p. 88) that 'high' imagers will in fact perform worse in the picture memory condition involving simultaneous performance of the internalised cognitive task.

(vi) The internalised cognitive task.

Few subjects scored even a small number of correct solutions on this task over the 50 trials. The main obstacle was one of time, subjects taking excessive time to solve the mental arithmetic problem. However, when given the problem, subjects in all cases conscientiously initiated an attempt to reach a solution. As emphasised earlier, for the purposes of the present experiment it was necessary only that subjects utilise their cognitive capacity to attempt a solution to the problem, i.e. that some proportion of their available processing capacity was being utilised to prevent the entire capacity being dedicated to the picture memory task. It is clear from the significance of the results, and the qualitative nature of the error patterns found in the experiment that this aim was achieved. (see p.120-124)

4.15 Preliminary conclusions.

The theoretical concepts developed earlier in this thesis are strongly and significantly supported by the empirical evidence of the present experiment. Performance patterns of subjects obtained by quite different analyses of both the picture memory and the imagery data confirm a considerable spectrum of separate predictions,each independently derived from the theory.

In order to further confirm the present results, and to investigate whether the effects observed are resistant to changes in methodology, a second more powerful experiment using additional controls and larger numbers of subjects was carried out. This is reported in the next chapter, together with further discussion and conclusions in relation to both experiments.

CHAPTER V

5.1 Some new, and apparently powerful, effects were demonstrated in the experiment reported in the previous chapter. The results of that experiment were significantly in accordance with the predictions derived from the present theoretical approach. In order to confirm further the validity of the theoretical conclusions drawn from this empirical evidence, and to determine whether the effects observed are resistant to methodological changes, a second, fundamentally similar experiment was carried out.

5.2 Under the previous experimental testing procedure, the experimenter had no overt feedback as to the continuing nature of the internalised cognitive processing employed by subjects in the dual-task condition. Further, while the subject was attempting to solve the mental arithmetic problem in silence, the experimenter had no way of knowing whether the subject's ongoing stream of information processing referent to the problem was interrupted when the picture was presented, the subject switching his attention to the processing of visual sensory information. The subject could have devoted a maximum amount of his cognitive processing capacity to the picture memory task for the duration of exposure of the picture, returning to the mental arithmetic problem only after the appropriate decisions had been made with regard to the identification of the picture.

Because of the practical necessity to limit the time period during which the subject could work on the internalised cognitive task on each trial, the correctness or accuracy of the subject's internalised processing associated with the solving of the mental arithmetic problem could not be evaluated. For example, if the exposure of the slide caused the subject to lose track of the problem, and prevented him ultimately reaching a correct solution, the experimenter had no means of ascertaining this. Also, even if the maximum time period allowed for solving the mental arithmetic problem were considerably increased, enabling the subject to reach a solution, and if the resultant answer were correct, it could still not be determined unequivocally whether or not the subject continued to work on the problem for the duration of exposure of the picture, or whether the occurrence of the picture caused the subject to lose track, and recommence solving the problem from scratch.

On the basis of the experience of the first experiment, the mental arithmetic task appeared to fulfil its intended purpose most successfully. However, to extend the time period to the extent required for a solution to be reached on a majority of occasions would have made the dual-task situation even more arduous for subjects than it was. A pilot study showed that the extended and sustained period of intense concentration required in such a situation would undoubtedly introduce considerable extraneous effects, such as fatigue and reduction in task motivation, especially towards the end of the long testing session required. For these reasons, together with the problem of validity of interpretation of successful results discussed above, it was considered undesirable to increase the time period allowed for the mental arithmetic problem.

It is emphasised that the results of the subjects in the experimental group in the previous experiment clearly confirm that the internalised cognitive task was having the predicted effect on subject's performances. This finding supported the post-experimental statements by the subjects that they were obeying the experimental instructions to the best of their abilities. The subjects were known to be highly motivated, and their statements to this effect were considered to be highly credible. However, it is conceivable that the lack of overt control over the above aspects could have facilitated better performance on the part of the experimental subjects. In any case, because the main experimental findings were to be replicated with larger numbers of subjects, whose high degree of motivation could not be guaranteed, and because the validity of the findings are increased by more powerful controls over possible extraneous variables, it was considered desirable to change the previous methodology with these aims in mind.

5.3 In order to overcome all the problems outlined above, the following change in experimental methodology was adopted:-

Subjects in the dual-task condition were required to think aloud for the entire period during which they were attempting to reach a solution to the mental arithmetic problem. This thinking aloud procedure has been very extensively and effectively utilised by Newell, Shaw and Simon in their well-known research investigations of human problem solving. Much of this work has employed the subject's vocalisation of his thought processes as a primary data base from which to make inferences concerning the fundamental nature of cognitive processing in difficult problem solving situations. From this information, these investigators have developed computer programs incorporating the heuristics typically utlised by subjects to simulate the essentials of human problem solving. All this extensive research, which now spans close to two decades, is reviewed, summarised, and extended, in the recent book by Newell and Simon (1972) entitled 'Human Problem Solving'. A transcription of a typical subject's vocalisation in a cryptarithmetic problem solving situation is provided in Appendix 6.1 of this book (p. 230).

In the present context, the requirement that the subject think aloud has a number of advantages with respect to experimental control:-

(1) It enables the experimenter to affirm on each trial that the subject is continuously and meaningfully attempting to solve the problem given.

(2) The methodology and content of the subject's attempt to solve the problem can be monitored by the experimenter, who can progressively check the accuracy of the subject's operations.

(3) Most importantly for the present experiment, the continuity of the subject's cognitive processing referent to the problem can be verified by the experimenter. The effect of a switching of attention to the processing of the picture information will be clearly reflected by a discontinuity in the ongoing vocalisation of the subject. Thus, if the subject is proceeding smoothly with the problem, and this continuous flow of vocalisation ceases momentarily when the experimenter chooses to present the picture, it can be assumed that the subject's attention has switched to processing the visual sensory information.

(4) By monitoring the subjects ongoing cognitive processing, the experimenter can choose to display the

picture at an instant in which the operations being performed by the subject are most difficult. That is, in the sequence of arithmetical multiplications necessary to solve the two-figure multiplication problem given, the picture can be exposed by the experimenter when it is clear that the subject is embarking on the next of these stages, rather than at the end of one such stage, when there is typically a slight pause in processing.

In summary, the adoption of this change in methodology provides a powerful check that the subject is adhering to the experimental instructions throughout each trial in the dual-task situation.

5.4 In the previous experiment, the homogeneous pictures in each set were grouped together in the testing situation. This could clearly have had the effect of reducing the subjective uncertainty with respect to all pictures subsequent to the first one within each homogeneous set. According to the present theory, this would reduce the proportion of real sensory information that the subject needed to process in order to identify the expected stimulus category, with a corresponding increase in the number of E_2 errors. This would have enhanced the difference on the E_2 error index between the experimental and control groups. It is considered, however, that this was unlikely to be the case in the previous experiment for the following reasons:-

(1) Subjects were not provided with any feedback regarding the correctness of their responses on the picture memory task. Therefore, even if, for a particular homogeneous set, a subject had responded in the affirmative to the identification of two pictures as those seen in the

learning set, he had no way of knowing whether or not these two responses were correct. Consequently, if a picture was presented subsequently in the same set, and the subject thought it was one of the overlearned set, he would answer accordingly, regardless of the nature of his previous responses.

(2) At each trial, subjects were always attempting to process sufficient visual information to identify unambiguously _specific_ pictures, in addition to the heterogeneous category. This requirement was referent to each picture as all pictures were different, and was therefore logically unaffected by sequential probability factors.

(3) The pattern of results for the experimental group in the previous experiment, in which 76% of E_2 errors consisted of incorrect affirmative responses to the identification of specific pictures, is clear evidence that subjects were not making decisions on the basis of their earlier responses. That is, even though the homogeneous sets were grouped, subjects were not simply responding in the affirmative twice for each homogeneous set of pictures. Subjects were tending to make _more_ than two affirmative identifications per set, even though they were aware that, for each set only two of the pictures had been overlearned.

Although it appears unlikely, in view of the results of the previous experiment, that the grouping of the homogeneous slides had any significant qualitative or quantitative effects on subjects' cognitive processing strategies, any such possibility can be effectively eliminated by completely randomising the sequence of all pictures in the picture memory testing situation. The subject then has no way of consistently predicting the occurrence of particular stimulus categories or particular pictures, the real probability of occurrence of any stimulus category being 0.1 and that of the occurrence of a picture of the learning set being 0.4, on each trial.

The randomisation of all the pictures also prevents the subject becoming aware of the number of pictures within each homogeneous set, so that he cannot utilise such information in any response strategy. Comparison of the results obtained by the experimental groups in the randomised and non-randomised testing conditions will indicate whether the non-random picture grouping used in the previous experiment was having any significant effect on subject performance.

5.5. Although there were no apparent sex differences in any of the imagery or picture memory performance data obtained in the previous experiment, practical difficulties prevented an equal balancing of sexes within each group. If there was any statistical artifact associated with this aspect, which is most unlikely, it can be overcome in the present experiment by ensuring equal numbers of each sex within each group.

5.6 The main effects observed in the last experiment were sufficiently powerful to facilitate highly significant statistical differences in performance between experimental and control groups with the relatively small numbers of subjects used. However, the reliability and validity of these empirical findings will be substantially increased if the effects are replicated with larger numbers of subjects.

In view of all the foregoing considerations a second experiment was carried out incorporating the methodological changes described above. The theoretical basis of this second experiment, and the main experimental hypotheses to be tested are precisely the same as for the first experiment, as reported in Chapter IV.

5.7 Method

(i) Apparatus

The apparatus used in the experiment was identical to that employed in the previous experiment.

(ii) Subjects

21 undergraduate and postgraduate students of the University of St. Andrews (10 male, 11 female) participated in the study. All had normal corrected vision and no optical defects. None of the subjects had served in the previous experiment, and none had any knowledge in relation to the purpose of the experiment.

(iii) Procedure

The experimental procedure in relation to the administration of the VVIQ, the presentation of the learning set of 20 pictures from the 10 stimulus categories, and the recording of subject's verbal descriptions of these pictures was identical to that employed in the previous experiment.

After the recording of the subject's verbal descriptions of the overlearned pictures, and checking that the subject had described all the sets of pictures presented in the learning set, recognition performance was tested.

For the reasons outlined earlier, the entire set of 50 slides had been pseudo-randomised. This was done by numbering the slides 1 to 50 and, using sets of random numbers within this range generated by a Nova 1220 computer, each picture was allocated a random position in the testing sequence. The constraints imposed upon this randomisation were:- (a) that no two homogeneous pictures from the same stimulus category could be presented consecutively; and, (b) that the 5 homogeneous slides from the 10 categories were relatively evenly distributed throughout the set of 50.

(A) Control group

The recognition testing procedure for the control group was the same as for the previous experiment. The instructions read to the subjects were the same as used previously, except that the following statement was added at the end of the first paragraph of the experimental instructions (p.96): "The order of presentation of the pictures in this larger set is completely random". The experimenter recorded the subjects' recognition performance on the two error indices, E_1 and E_2 , as previously.

(B) Experimental group

The testing procedure for this group was essentially the same as that used in the previous experiment. However, for the reasons outlined earlier, this time the subject was required to think aloud during his attempt to solve the mental arithmetic problem. Accordingly, the additional instructions to subjects, referent to this aspect of the testing were as follows:-

"In the next part of the experiment, I am going to give you some mental arithmetic problems to solve. These problems will be relatively difficult, but certainly not impossible, and I want you to try as hard as you possibly can to attempt to solve them. This is extremely important. The experiment requires that you try as hard as you can.

Now, while you are attempting to solve each problem, I want you at all times to think aloud. In other words, you must tell me exactly what you are thinking, and how you are going about solving the problem. I want you to keep this stream of comments flowing smoothly, with no hesitations or periods of silence. This is very important. You must try and say aloud everything that you are thinking. Do you understand? Do you have any questions?

We will now have a few practise problems to get you accustomed to this procedure".

Several such practice trials were given. The main part of the testing session was commenced when the experimenter was satisfied that the subject was conversant with the thinking aloud procedure, and could achieve a smooth flow of vocalisation coincident with his attempt to solve the mental arithmetic problem.

The recognition performance of the experimental group subjects was then tested as in the previous experiment. However, in this case the experimenter listened carefully to the subject's vocalisation of his attempt to solve the problem, and by this means, as far as possible, kept track of what the subject was doing. Any interruption to the flow of the subject's vocalisation occurring on presentation of the picture was noted. Further, the picture was presented at a time when the subject was carrying out multiplication operations (see p.123).

Instructions to subjects in the experimental group were those used in the previous experiment except that, as for the control group, the following statement was added. "The order of presentation of the pictures in this larger set is completely random." The instructions with regard to the testing procedure were also changed slightly and this paragraph now read as follows:-

"Now, before each picture is presented, I am going to give you a mental arithmetic problem like the ones you have just practised. It will be a difficult but not impossible problem, and I want you always to try as hard as you possibly can to <u>attempt</u> to solve it. Remember, you must think aloud <u>all</u> the time, and you must keep your flow of words as continuous and as smooth as possible. You must not stop speaking when the picture appears on the screen. I will be listening carefully to you <u>all</u> the time, so that I will know whether or not you are concentrating on the problem.

If you get the answer to the problem, we will stop, and you will then tell me about the pictures. After I have recorded the results we will go on to the next trial. As soon as I give you the problem, you must commence to solve it and all the time keep looking at the screen where the picture will be projected. The picture will be presented for one second at some random time after you have commenced to solve the mental arithmetic problem. If at any time you want a rest break, tell me and we will stop for a short period. Remember, you must think aloud <u>all</u> the time.

I will read these instructions again, as it is essential that you understand the procedure exactly. Do you have any questions?"

During testing of both experimental and control groups, subjects were given a short rest break after half the slides had been presented, with additional similar rest periods given at the subject's request. The testing sessions were somewhat more arduous than the previous experiment; however, as before, the experimenter at all times attempted to maintain a relaxed minimum-stress atmosphere in the testing room.

At the end of the session, subjects were interviewed and invited to comment on any aspect of the experiment.

5.8 Results and preliminary discussion

(i) Picture Memory

The recognition performance of subjects is shown in table X.

TABLE X

Group	Subject	Sex	E_1	E_2
Control (N = 11)	RMcC	F	0	14
	MP	F	0	8
	AC	F	0	6
	GB	F	0	8
	CO	F	0	7
	DM	F	0	6
	LJ	M	0	7
	KL	M	0	7
	DKM	M	0	10
	CM	M	0	6
	RM	M	0	2
	Mean/S.D.		0/0	7.36/2.80
Exptl. (N = 10)	ER	F	0	13
	GC	F	0	13
	FM	F	0	15
	VJ	F	0	16
	AP	F	0	13
	AH	M	0	16
	IW	M	0	14
	TL	M	0	12
	IM	M	0	16
	JL	M	0	19
	Mean/S.D.		0/0	14.7/2.00

Key: E_1 = number of errors of recognition of the stimulus category.

E_2 = number of errors in relation to identification of specific pictures.

As in the previous experiment, no subject in either group made any errors in the identification of the stimulus category (E_1). Subjects in the control group again, as predicted, made a small number of identification errors with respect to specific pictures within the homogeneous sets (E_2). (mean E_2 errors = 7.36; SD = 2.80). Subjects scored a mean of 85.28% correct identifications of specific pictures, which was only very slightly less than, and not significantly different from, the performance achieved by the control group in the previous experiment. A high level of recognition performance was achieved which was consistent across subjects, the randomisation of pictures in the recognition test having no apparent effect on performance in the control situation.

Performance of subjects in the experimental group was also consistent across subjects. However, once again, the mean number of E_2 errors made by subjects in the experimental group was twice as great as the mean number of E_2 errors made by the control group. (mean E_2 errors = 14.7; SD = 2.00). The variances of both groups were homogeneous ($F = 1.95$; $v_1 = 10$; $v_2 = 9$), and a normal 't' test was appropriate to test the statistical significance of the difference between the sample means.

The difference between the mean number of E_2 errors made by the experimental and control groups was found to be significant at the 0.002 level ($t = 6.50$; 19 degrees of freedom).

These highly significant results provide further strong support for the experimental hypotheses derived from the present theory, (i.e. that subjects in the dual task condition would make more specific picture errors (E_2) than those in the control condition, who could dedicate all their cognitive processing capacities to performance of the recognition task). The additional controls incorporated in this experiment had no effect on the degree of significance of the difference in E_2 errors between the experimental and control groups, nor on the real values of this index of memory performance. This almost exact replication of the results of the earlier experiment confirms that subjects in that experiment were obeying the experimental instructions, and not formulating their response strategies on artifacts referent to the adjacent grouping of all the pictures in each homogeneous set.

The results of this second experiment again show that the simultaneous performance of the internalised cognitive task with the picture memory task has the empirical effect on performance predicted by the present theory.

On the basis of the E_1 errors alone, there was no difference between the performances of the experimental and control groups, each achieving error-free performance. In the randomised picture situation, the complete lack of errors of category identification is proof that subjects were processing at least a sufficient proportion of the real visual sensory information to identify this aspect correctly. The randomisation of the pictures made it impossible for subjects to consistently guess the occurrence of specific categories. The mean percentage of correct E_2 responses for the experimental group was 70.6%.

(ii) Analysis of error patterns in picture memory performance

The total percentages of errors made by all subjects with respect to the homogeneous pictures in each stimulus category are shown in table XI.

TABLE XI

Stimulus category	1	2	3	4	5	6	7	8	9	10
% errors, control group	21.81	0	12.7	0	29.0	18.1	5.4	23.63	32.72	3.63
% errors, exptl. group	40	12	20	12	44	48	28	32	36	22

Graphing the results given in table XI shows that, as in the previous experiment, the error patterns for both experimental and control groups are very similar (Fig. 6). Once again, these patterns covary closely ($r = 0.8$), and to virtually the same degree as the equivalent error patterns of the earlier experiment. This shows that the relative difficulty of the homogeneous sets forming the different categories was not affected by the overall randomisation of the pictures.

This finding further emphasises the point made earlier (p.104), that the effect of the simultaneous cognitive task is not simply to interfere with memory, i.e. in that on each trial the subject makes his decisions with regard to the picture, but the performance of the internalised cognitive task causes him to forget all about them. If this were the case, there would be no reason for the experimental and control error patterns to covary; all categories should present equal difficulties in the dual-task situation. The results show clearly that the recognition performance decrement of the experimental group is not a result of such a failure of memory, rather it is consistent with a reduction in the amount of real sensory information which is processed. There is no fundamental change in the qualitative

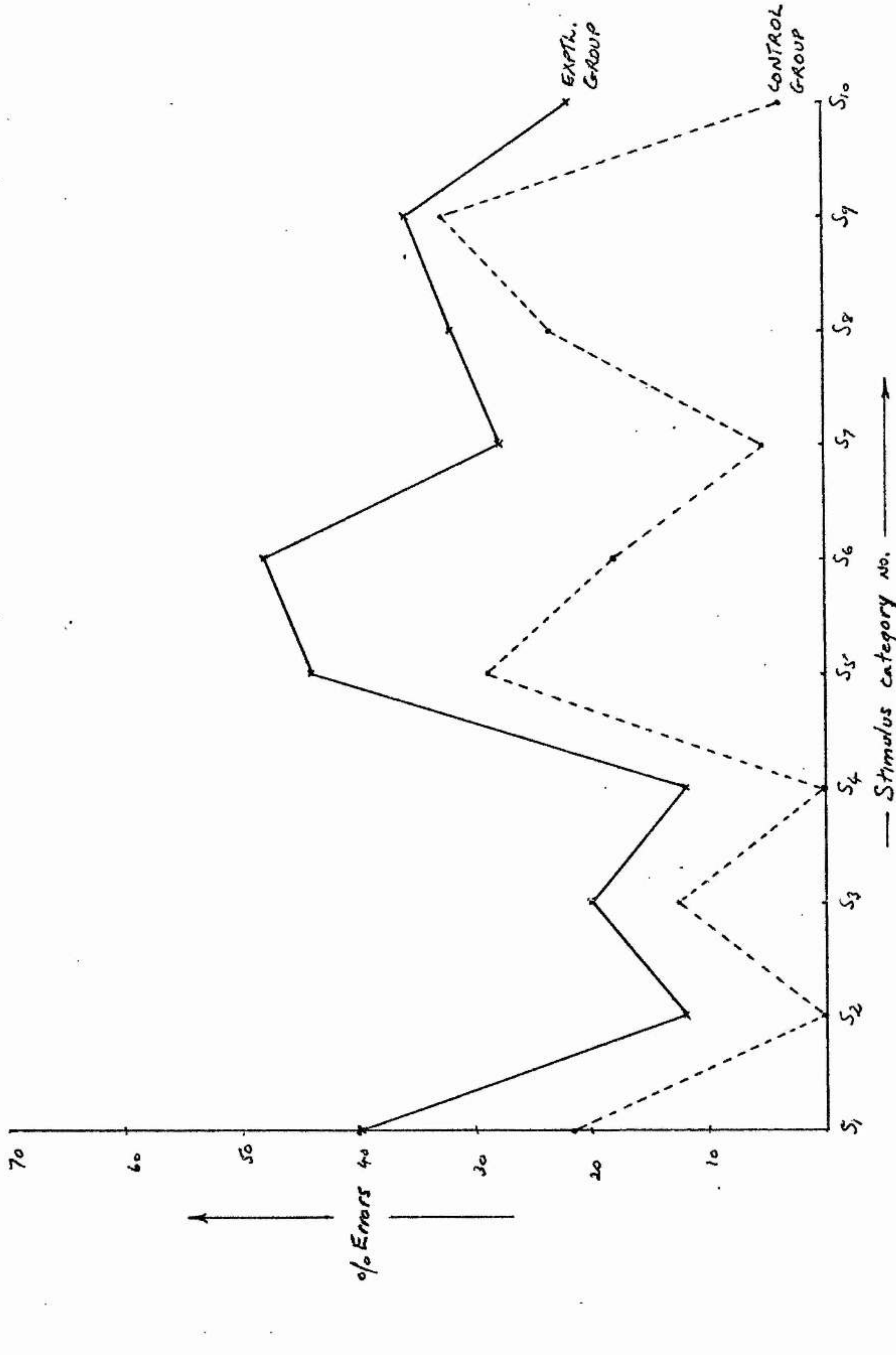
EXPTL. GROUP
CONTROL GROUP
70
60
50
40
30
20
10
% Errors
S_1
S_2
S_3
S_4
S_5
S_6
S_7
S_8
S_9
S_{10}
Stimulus category No.

FIGURE 6.

nature of the individual processing strategies referent to performance of the picture memory task. Whatever may be the individual differences in these response strategies, the consistency of performance across subjects in both groups shows that the resultant global performance levels achieved by subjects on this task are extremely similar.

(iii) Order of free recall of the 10 stimulus categories in relation to errors on these categories.

Reference to Fig 4. shows that, even though the pictures were randomised, categories S_6, S_5, S_9, S_8 and S_1 were again associated with the highest E_2 error rates for both experimental and control groups. For the reasons outlined previously (p.106), the relationship between the order in which the stimulus categories were recalled and the errors relating to those categories was investigated. No subject in the second experiment failed to describe correctly all the sets of pictures shown in the learning set, showing that the pictures had been well overlearned.

The high degree of similarity of the error patterns of both groups again enables the total numbers of errors by all subjects referent to each category to be compared with a weighted index of free recall rank order for that category

Using the procedure outlined previously (p.107), tables XII and XIII are obtained.

The Spearman rank-order correlation coefficient between the rank order of the weighted rank index and the rankings of the total errors for each category is $r_s = 0.18$. This statistic indicates that there is no significant relationship between E_2 errors and order of free recall for the 10 stimulus categories. The r_s obtained here is lower than the equivalent r_s obtained in the previous experiment, which, although not significant was

TABLE XII

Calculation of weighted rank index

	Rank 1	2	3	4	5	6	7	8	9	10	Weighted rank index
S_1	13	0	0	2	2	1	1	0	0	2	64
S_2	2	9	2	1	1	1	1	1	2	1	84
S_3	1	2	1	4	1	2	3	4	2	1	122
S_4	1	0	1	2	2	2	5	2	2	5	152
S_5	1	0	4	3	0	1	2	4	3	3	134
S_6	1	1	0	0	3	2	1	5	5	3	152
S_7	0	1	2	7	1	2	0	2	2	4	127
S_8	1	2	2	1	4	6	2	3	0	0	107
S_9	0	2	4	0	5	0	2	1	4	2	119
S_{10}	2	2	4	0	3	3	3	1	2	0	98

The numbers in each cell show the frequency with which all subjects free-recalled the particular category at that particular rank order. e.g. 13 subjects free recalled category S_1 first; 3 subjects free recalled category S_{10} seventh, etc.

TABLE XIII

Weighted rank index and errors for all stimulus categories

Category	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Rank index	64	84	122	152	134	152	127	109	119	98
Total errors on the category	32	6	17	6	38	34	17	29	36	13

somewhat greater ($r_s = 0.51$), indicating that for the randomised picture situation there was only the slightest tendency for fewer errors to be associated with stimulus categories described earlier in the free-recall situation.

The rank order correlation between order of presentation of the stimulus categories in the learning set and the order in which the categories were free recalled was $r_s = 0.19$, which was not significant, showing no important tendency for categories presented first to be free recalled earlier.

The above results illustrate even more strongly than the earlier experiment, that any possible order effects were eliminated by the overlearning of the stimulus pictures and the power of picture memory.

(iv) Errors of recognition of the overlearned pictures.

The number of identification errors made by subjects in relation to the particular pictures in the overlearned set, together with the total number of E_2 errors made by each subject are shown in table XIV.

For the control subjects, errors in relation to the identification of pictures in the learning set formed a mean of 36.65% of the total number of errors made by each subject. In some contrast to the previous experiment, errors in relation to pictures in the learning set formed a mean proportion of 45.1% of the total errors made by each subject in the experimental group. (vs 25.81% in the earlier experiment). In the present case, the difference between these mean percentages for the experimental and control groups was not significant at the 0.1 level ($t = 1.14$; 19 degrees of freedom). There was no statistically significant difference between the groups on this aspect, both groups making a similar proportion of errors of identification of the specific pictures in the learning set.

TABLE XIV

Errors with respect to the particular pictures memorised.

Group	Subject	Sex	Total errors w.r.t. pictures in the learning set (A)	Total E_2 errors (B)	A/B%
Control (N = 11)	RMcC	F	7	14	50.0
	MP	F	1	8	12.5
	AC	F	3	6	50.0
	GB	F	4	8	50.0
	CO	F	4	7	57.1
	DM	F	2	6	33.3
	LJ	M	3	7	42.8
	KL	M	1	7	14.2
	DKM	M	1	10	10.0
	CM	M	2	6	33.3
	RM	M	1	2	50.0
				Mean	36.65%
Exptl. (N = 10)	ER	F	5	13	38.4
	GC	F	10	13	76.9
	FM	F	7	15	46.6
	VJ	F	11	16	68.7
	AP	F	3	13	23.0
	AH	M	8	16	50.0
	IW	M	6	14	42.8
	TL	M	5	12	41.6
	IM	M	6	16	37.5
	JL	M	5	19	26.3
				Mean	45.1%

Comparison of these findings with the equivalent results of the previous experiment suggests that the reason for the change in the proportion of errors made in relation to the overlearned pictures by the experimental group in the present experiment is that the randomisation of the pictures has had the effect predicted earlier (p.112). It appears that, although on the primary criteria, performance of the experimental groups in both experiments was virtually identical, on this particular parameter there was a significant and qualitative difference in the patterns of performance. The difference between these means for the experimental groups in the two experiments was significant at the 0.05 level ($t = 2.433$; 14 degrees of freedom).

In the non-random situation, the predictability of parts of the sequence within each homogeneous set of pictures meant that, on these occasions, subjects need process only a minimum amount of real sensory information to confirm the presence of the stimulus category which they knew would certainly occur. Consequently, under these conditions, more processing capacity could be utilised in performance of the mental arithmetic task, and a greater proportion of pictures on which E_2 errors were made would be perceived as those previously overlearned.

The results obtained in the randomised picture situation show no qualitative differences in performance patterns between the experimental and control groups. The randomisation of the pictures eliminates the only difference between the experimental and control group performance patterns observed in the earlier experiment. This further emphasises the notion outlined previously (p.104) that the effect of the simultaneous performance of the internalised cognitive task is one of a pure negative shift in the level of picture memory performance of the experimental group. The performance patterns of the two groups in the present experiment were qualitatively exactly the same for both groups. The effect of the mental arithmetic task was to reduce the amount of real visual sensory information which was processed on many trials in the dual-task situation, the E_2 errors being a result of this. There was no fundamental change in the nature of the cognitive processing referent to the picture memory task in the dual-task situation.

(v) Sex Differences

There were no significant differences in picture memory performance between male and female subjects in either the experimental or control groups.

(vi) The imagery data

As in the earlier experiment, the imagery data are extremely interesting. VVIQ scores for all subjects, together with E_2 errors are shown in table XV.

As noted in the previous experiment, conditions for administration of the VVIQ were extremely good, subjects again taking 20 to 25 minutes to complete the VVIQ. Reference to table XV shows that, for both groups, there was no significant difference between the mean imagery scores for eyes open and eyes closed conditions. There were no significant differences between the mean VVIQ scores obtained for the experimental and control groups. Over all subjects, the correlation between total VVIQ scores for the eyes open and eyes closed conditions was found to be only $r = 0.56$, exactly the same as for the previous experiment. The various relationships between E_2 errors and imagery scores obtained under the eyes open and eyes closed conditions, in addition to the total imagery score, were investigated as in the earlier experiment.

TABLE XV

VVIQ Scores for all subjects

Group	Subject	Sex	E_2	Total VVIQ scores: Eyes open	Eyes closed	Total	Mean Rating
Control (N 11)	RMcC	F	14	33	45	78	2.43
	MP	F	8	48	44	92	2.87
	AC	F	6	36	42	78	2.43
	GB	F	8	32	27	59	1.84
	CO	F	7	46	49	95	2.96
	DM	F	6	53	52	105	3.28
	LJ	M	7	46	55	101	3.15
	KL	M	7	28	46	74	2.31
	DKM	M	10	47	42	89	2.78
	CM	M	6	32	30	62	1.93
	RM	M	2	51	47	98	3.06
	Mean/SD		7.36/ 2.80	41.09/ 8.522	43.54/ 8.06	84.63/ 14.80	2.64/ .46
Exptl. (N 10)	ER	F	13	40	52	92	2.87
	GC	F	13	44	65	109	3.40
	FM	F	15	50	36	86	2.68
	VJ	F	16	28	26	54	1.68
	AP	F	13	42	45	87	2.71
	AH	M	16	46	44	90	2.81
	IW	M	14	56	43	99	3.09
	TL	M	12	41	50	91	2.84
	IM	M	16	51	62	113	3.53
	JL	M	19	30	26	56	1.75
	Mean/SD		14.7/ 2.00	42.8/ 8.36	44.9/ 12.53	87.7/ 18.43	2.73/ .57

The following results were obtained:-

(a) Control group

Product-moment correlation between E_2 errors and:-

(i) Total VVIQ score - $r = -0.24$

(ii) Eyes open VVIQ score - $r = -0.33$

(iii) Eyes closed VVIQ score - $r = -0.08$

These correlations are small and not individually significant, although they are all negative.

(b) Experimental group

Product-moment correlation between E_2 errors and:-

(i) Total VVIQ score - $r = -0.55$

(ii) Eyes open VVIQ score - $r = -0.34$

(iii) Eyes closed VVIQ score - $r = -0.58$

In this case the inverse correlations are comparatively high, two being greater than 0.5. The relatively large absolute values of these correlations, together with their negativity confirm again the prediction derived from the theory (p. 88) that 'high' imagers will tend to perform worse in the picture memory condition involving simultaneous performance of the internalised cognitive task.

In the equivalent analysis in the earlier experiment (p. 114), it was suggested that the cognitive processing requirements of the picture learning and memory tasks used in the experiment were well within the capabilities of all subjects. Consequently, in the control situation all subjects performed extremely well, the index of performance provided by the memory task not being sensitive enough to discriminate effectively between 'good' and 'poor' visualisers at the level of performance required.

In the dual-task condition performance is closer to the limits, and it was suggested that the hypothesised relationship between vividness of visual imagery and picture memory performance would be more likely to be apparent in this situation. In the previous experiment, this predicted relationship became apparent when the E_2 errors on only the five most 'difficult' stimulus categories were considered, the variance contributed by errors on the 'easier' categories masking the covariance between vividness of visual imagery and picture memory performance.

However, in the present experiment because of the larger number of subjects, the predicted relationship is clearly apparent when all categories are included in the analysis.

However, to enable a direct comparison with the results of the earlier experiment, the above analysis was carried out with respect to total errors on the 'difficult' categories, S_1, S_5, S_6, S_8 and S_9 only. The following results were obtained:

(a) Control group

Correlation between E_2 errors and:-

(i) Total VVIQ score $r = 0.38$

(ii) Eyes open VVIQ score $r = 0.53$

(iii) Eyes closed VVIQ score $r = 0.14$

(b) Experimental group

Correlation between E_2 errors and:-

(i) Total VVIQ score $r = -0.27$

(ii) Eyes open VVIQ score $r = -0.14$

(iii) Eyes closed VVIQ score $r = -0.3$

These results are extremely interesting, as while the absolute values of the experimental group correlations are reduced they all remain negative. However, on these 'difficult' categories, all the equivalent correlations for the control group become positive, with one value reaching 0.53. Thus, this analysis reveals a clear divergence of performance between the experimental and control subjects when the performance requirements of the task are greater. On these 'difficult' categories, good picture memory performance tends to be associated with a greater degree of vividness of visual imagery as determined by the VVIQ. This finding is in accordance with Mark's (1973) results, i.e. that 'good' visualisers perform <u>better</u> on picture memory tasks than 'poor' visualisers. In contrast, as predicted by the present theory, in the dual-task situation a greater degree of vividness of visual imagery, as determined by the VVIQ, is associated with <u>poorer</u> performance on the picture memory task.

The above theoretical considerations, and the outcome of the associated analysis related to two separate performance situations provide considerable evidence in support of Mark's claim for the validity of the VVIQ as a useful index of vividness of visual imagery. Quite different predictions derived from analysis of the two separate experimental situations according to the present theory were confirmed. This analysis was concerned with the functional role of the imagery system, and the transference of these theoretical concepts into empirical predictions was dependent upon the validity of the VVIQ as a quantitative index of imagery. The confirmation of these predictions indicates that the VVIQ is both a valid and useful 'measure' of individual differences in vividness of visual imagery.

(vii) <u>Sex differences</u>

There were no significant differences between mean VVIQ scores for male and female subjects in either the experimental or control groups.

(viii) The internalised cognitive task

As in the previous experiment, few subjects scored even a small number of correct solutions on this task over the 50 trials, because of the limited time allowed for each problem. However, all subjects performed extremely well and conscientiously in the experiment. The requirement of thinking aloud presented few difficulties to subjects. Monitoring of the subjects' vocalisations by the experimenter showed that, on the whole, the subjects were obeying the experimental instructions to the best of their abilities. The subjects maintained a smooth flow of vocalisation when the slide was presented. Occasional prompting from the experimenter between trials ensured that this requirement was kept in mind at all times by the subjects. The sustained concentration and very long testing sessions required for this experiment were mentally fatiguing for both subject and experimenter, but no subject abandoned meaningful attempts to solve the mental arithmetic problems, even towards the end of the testing session, and there was no tendency for errors to increase over the testing time period. The 'thinking aloud' requirement fulfilled its intended purpose most successfully.

5.9 Conclusions

The experiment reported in this chapter replicated almost exactly the findings of the similar experiment reported in chapter IV. The effects observed proved resistant to changes in methodology, and the adoption of more powerful and extensive controls, together with the larger numbers of subjects in the present experiment, confirmed and increased the validity of the previous findings over a wide range of different analyses.

The main results of the two experiments are highly significant, and strongly support the theoretical concepts developed earlier in this thesis, together with the experimental strategies and methodologies derived from these concepts. Some new effects have been demonstrated which, in addition to their bearing on the present theoretical approach, are relevant to other areas of investigation.

Concerning picture memory, for example, the results of the experiments using the two-stage recognition procedure in relation to a series of heterogeneous stimulus categories, each represented by sets of homogeneous pictures, indicate that, although picture memory is undoubtedly extremely powerful, the argument of Goldstein and Chance (1970), that the power of picture memory has been somewhat overestimated in the literature, is correct. (see p.79). The present experiments have demonstrated that two picture memory performances based only on recognition of heterogeneous pictures may appear to be identical, when the use of a second error index in relation to the identification of a previously learned picture in its totality may show that the two performances are, in fact, significantly different.

Secondly, the successful utilisation of the VVIQ indicates the worth of its use as a research tool in experiments concerned in any way with visual imagery. The present experiments go considerably further than typical studies which attempt only to relate good visual memory, or visual learning performance, to high levels of vividness of visual imagery. It appears that the index of imagery provided by the VVIQ is sufficiently robust to be usefully applicable to a wide range of experimental situations.

The present results are also relevant to the "disproof" of the single channel hypothesis claimed by Allport, Antonis and Reynolds (1972). In a dual task condition involving the simultaneous shadowing of speech presented through headphones and the learning of pictures, it was found that subjects could apparently "attend to and repeat back continuous speech at the same time as taking in complex, unrelated visual scenes." (ibid. p.225). However, in this experiment sets of only 15 unrelated, heterogeneous pictures were shown to the subjects, and the experimenters "tested how much (the) subjects had taken in" by a forced-choice recognition procedure. Subjects had only to respond either "yes" or "no" to a given picture, according to whether or not they believed it to be one of the items originally learned. The investigators state:

"Recognition of the pictures was much less affected by simultaneous auditory shadowing; one subject showed no loss of accuracy, and three made only one or at most two more errors under divided than under undivided attention." (ibid. p.229).

The results of the present experiments showed that on the basis of recognition of heterogeneous picture categories alone, there was no difference in recognition performance between subjects tested under undivided and divided attention conditions. However, when the second index of recognition performance, (E_2), relating to specific picture errors, was taken into account, the highly significant performance differences between the divided and undivided attention conditions became apparent. The clear implication is, therefore, that the measure of picture recognition performance used by Allport et.al. was not sufficiently sensitive to pick up differences in performance between the divided and undivided attention conditions. The present experiments indicate that subjects may achieve what appear to be very high levels of performance on heterogeneous picture memory tasks without devoting all their processing capacities to these tasks. In view of the experimental evidence provided by the work of Loftus (1972), discussed earlier, and the results of the present experiments, it appears that the information content of the picture input may be very drastically reduced in the dual task situation. Allport et.al. mention this possibility as being a "way out" for the single channel hypothesis in explaining their results. They consider, though, that it is not very promising. However, as the preceeding discussion has indicated, this "possibility" should not be so readily dismissed.

CHAPTER VI

Vigilance - a cognitive approach.

6.1 The three experiments reported in the preceeding chapters have provided significant empirical evidence in support of the basic concepts of the present theory. This theory suggests a new approach to problems investigated over the last twenty five years or so, under the general category of "vigilance". Further, analysis of experimental work in this area carried out to date appears to provide strong support for the present theory. Comprehensive reviews of all recent work and the history of the extensive experimental research into vigilance phenomena are provided by Welford (1968) and Broadbent (1971).

In typical laboratory vigilance experiments, (which were originally derived directly from applied situations), subjects are required to detect and act upon the presence of faint and/or infrequent signals of low probabilities of occurrence over extended time periods. Welford (1968, p.19) states that the laboratory studies of the past two decades "have built up a complex, but reasonably coherent, picture of the association between, on the one hand, sensitivity and responsiveness as measured by behaviour, and on the other, physiological variables such as level of autonomic activity, and of the relationships of both to environmental conditions." He notes that these investigations have emphasised the importance of studying "continued performance as a function of time." (ibid)

Under certain conditions subjects often fail to detect the presence of target signals, even though the experimental situation requires that their primary attention be continuously focused on the potential signal source, (e.g. a radar screen). Recordings of eye movement patterns show clearly that many signals may be missed by subjects in spite of the fact that these signals occur well within the subject's visual field, the sensory information indicating the presence of a signal therefore reaching at least the retinal receptors. (Mackworth, Kaplan and Metlay, 1964). In a one-dial display task situation in the Mackworth et al experiment it was found that "every missed signal was fixated without being recognised" (ibid., p.397). Broadbent (1971) has termed this phenomenon "looking without seeing" (p. 42).

From the premises of the present theory, this finding is particularly significant. It shows that subjects fixating a specific visual target display pattern may not be consciously aware of portions of sensory information emanating from this pattern. In many instances, sensory information concerning the presence of a signal is physically received by, and available to the subject, but it is not utilised. In terms of the present approach it is considered that, in general, this sensory information does not become consciously available without an internalised reorganisation of the information flow dynamics of the cognitive system.

Investigators in this area do not appear to have overtly considered the vigilance problem from the particular cognitive viewpoint of the present approach. It is considered that the fundamental phenomena of vigilance-type situations are amenable to an analysis in terms of the present model. This analysis suggests new explanations and theoretical propositions which may be experimentally investigated. These explanations complement existing theoretical work, and deal with aspects of vigilance which existing theories do not attempt to explain. In very general terms, most existing theories are concerned with the "crucial question" (Welford, 1968, p.277) of why lapses of attention occur in vigilance tasks. In some contrast, the present theory is concerned with the explanation of what happens when these lapses occur - i.e. the manner in which the altered dynamics of the information flow within the organism may cause environmental sensory input to be disregarded.

The conscious and continued attention of subjects to the primary task in vigilance situations lapses because the tasks typically employed in such experiments are unstimulating, cognitively undemanding, and repetitive or monotonous. Post-experimental evidence from subjects indicates that during such tasks they start thinking as the task becomes increasingly boring. Thought processes involving daydreaming, imagining and fantasising are often concomitant with the monotony of the task situation (Antrobus, Singer, and Greenberg (1966)).

A reasonable explanation for subjects' failure to maintain high signal detection performance in vigilance tasks is that such tasks are essentially "laboratory artifacts", quite unlike, and with sustained performance requirements different from any task commonly encountered or likely to be undertaken in a subject's normal environment - i.e. in the evolutionary sense, man is not biologically adapted to the performance requirements of vigilance tasks. Therefore, when it does become necessary for human operators to perform vigilance-type tasks in real situations - such as manufacturing industry, defence, flying and driving, for example - applied psychological problems arise because of man's apparent inability to fulfil consistently the performance requirements of these tasks.

In terms of the present model, high levels of signal detection in vigilance task situations effectively require that a subject's cognitive processing system be maximally dedicated to the continuous analysis of his entire visual sensory information input. As discussed previously (p. 34), research evidence indicates that the conscious information processing capacity of this system is restricted. Thus, if part of this limited capacity system is utilised in thought, (even if the content of such thought is concerned with the task situation itself), the concomitant capacity available for analysis of visual sensory data is reduced. The two picture memory experiments reported in chapters IV and V have provided strikingly effective empirical demonstrations of this phenomenon.

In typical vigilance task environments, once the subject has become fully accustomed to the static visual sensory pattern of the task situation, especially those relating to the target display, and has stored this rapidly overlearned information in memory, such memory information can be utilised via the imagery system to meet the fundamental perceptual requirements of the task situation. At any given instant, the total amount of information concerned with conscious awareness of the basic task display may comprise phenomenally indistinguishable proportions of pattern information from memory and from the real sensory environment. The relative sizes of these proportions are related to the degree to which the subject's cognitive capacities are occupied by internalised thought processes, i.e. the degree to which his attention to the primary experimental task has lapsed.

The subjective probability of occurrence of the basic patterns concerning the target display (but obviously not the possible signal itself) very rapidly becomes, in effect, unity. From the theory, this means that a minimum amount of the sensory information environment needs to be sampled to confirm the presence of the expected pattern, thus allowing the bulk of the appropriate pattern information passed to conscious awareness to emanate directly from memory by means of the imagery system. In this sense, subjects in vigilance tasks continuously "see" the task display environment, i.e. in that they consciously experience its presence perceptually. However, while the nature of this conscious perceptual awareness may remain constant, the composition of the information content forming this awareness may vary substantially over time. The conceptual notions under consideration may be represented graphically as in Fig. 7.

This diagram schematically represents the information content of conscious perceptions of the same basic complex visual pattern A (e.g. a radar set, a T.V. screen etc...) at several consecutive instances in time - T_1, T_2, T_3, T_4. The shaded areas of these graphs represent the proportions of the pattern information content derived directly from the analysis of retinal sensory input data. The remainder of the pattern information (the unshaded area) comes from memory.

At T_1, the subject is utilising his maximum conscious capacity in the analysis of the sensory data input. At T_2, T_3, T_4, because the subjective expected pattern probability is extremely high, and because the capacities of the cognitive system are to an extent focused elsewhere, the greater proportion of this pattern information is coming from memory, direct sensory analysis having ceased when the presence of the expected pattern is confirmed. Clearly, then, if the same signal should occur at the "position" X shown in the displays, it will be detected at T_1 and T_3, but <u>not</u> at T_2 or T_4. Detection occurs at T_3 because of the contextual juxtaposition of the portion of the sensory

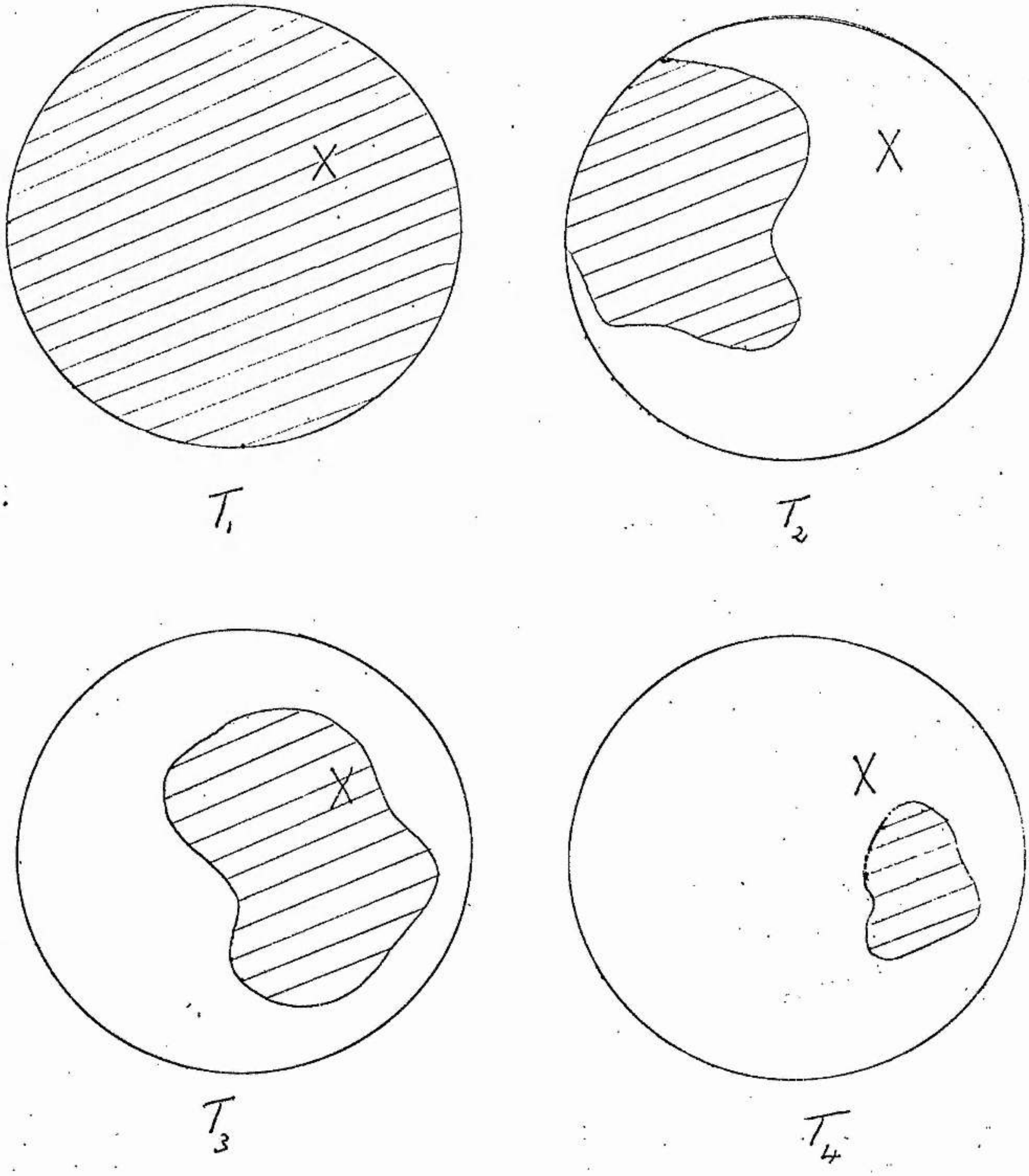

Fig. 7.

information input being analysed and the signal occurring at that instant. Thus, at times when the subject's conscious perceptual awareness is largely comprised of memory information, with minimal analysis of the concurrent sensory input, signals are less likely to be detected.

6.2 The foregoing analysis of vigilance-type situations leads to quite specific propositions amenable to experimental investigations, viz:-

Condition I: If over an extended time period a subject is repeatedly presented with the same complex visual pattern, which may or may not contain within it a given infrequent signal, Si, for the reasons outlined above, his detection performance should show the decrement over time normally observed in experiments in which the signal to be detected is a 'blip' on a blank cathode ray tube.

Condition II: However, if the task is restructured so that over the same extended time period the infrequent signals which must be detected may occur at random in any one of a given large set of complex visual patterns, each of equal but low subjective probability of occurrence, and if at every presentation the subject's task is both to identify the particular pattern and to detect the presence of a signal, detection performance in relation to the target signal should be significantly improved relative to condition I.

Where the time durations of the tasks are the same, and the task situations are in most respects identical, (i.e. subjects must register their identification of the display at each presentation in condition I, even though this pattern remains the same throughout), the theory predicts that the rate of detection of Si should be greatest in condition II, the performance level in this condition being directly dependent upon the size of the set of equally probable display patterns in which the target signal might occur. The greater the size of this set of possible patterns, the lower the probabilities of occurrence for each pattern. According to the present theory, because the accurate identification or recognition of patterns of low subjective probabilities of occurrence requires the processing of greater amounts of real sensory information in order to discriminate between the patterns, signals occurring in such patterns are therefore more likely to be detected. In other words, in this particular task situation, because at each presentation the subject must process more real visual sensory information in order to perform the pattern identification task accurately, as a spin-off from this task requirement he is more likely to detect the presence of a signal in the visual sensory information array if one happens to be present.

In contrast, in condition I, the same repeatedly occurring complex visual pattern becomes very rapidly overlearned (i.e. able to be completely specified from memory as an image). Consequently, even though the subject is required to identify the pattern at each presentation, because its probability of occurrence is unity, the amount of real sensory information that the subject must process which is necessary to confirm the presence of the expected pattern is greatly reduced. In this way, the processing capacity dedicated to this task is lessened, and the remainder of the available processing capacity is freed for utilisation by internalised thinking. According to the present theoretical analysis, because of this reduction of processing of real visual sensory information, the probability of detection of a signal which may be present in the pattern is lessened. The monotony of the sustained performance of such a single-pattern task over an extended time period should result in attention lapsing from the task, leading to a proportion of signals being missed, just as in the 'normal' vigilance task situation. At all presentations of the single, overlearned expected pattern, the subject should consciously 'see' the complete pattern, but this perceptual experience may consist of a high proportion of memory information combined with a relatively low proportion of real visual sensory information from the pattern.

In order to investigate the validity of the theoretical notions outlined above concerning vigilance-type task situations, the following experiment was carried out.

6.3 Method

(i) Apparatus

The construction and development of satisfactory apparatus to meet the particular requirements of the present experiment presented very considerable technical problems. These were finally resolved after an extended period of operational experimentation to evolve the most suitable equipment, recording methods and testing procedures.

The apparatus provided for the purposes of the experiment had to meet the following basic specifications:-

1) Complex visual patterns had to be repeatedly presented at constant exposure times and at regular time intervals over an extended period. For the same reasons as those outlined earlier in relation to the picture memory experiments reported in chapters IV and V, (p. 76), these complex visual patterns were to be in the form of 'normal' photographs, rather than line drawings or dot patterns. In the proposed control condition, the same photograph had to be presented

at each exposure for the duration of the experiment. In the experimental condition, a large number of photographs had to be presented in a random sequence for the entire period of the experiment. For both groups, the exposure time per picture was to be 1 second, with 5 seconds interval between each presentation.

2) An infrequent 'signal' had to occur intermittently at a random spatial position within any photograph used in the experiment. The signal had to be of sufficient clarity and contrast so as to enable it to be unambiguously discriminable, wherever it was located in the photograph. (i.e. it had to have a high visual signal to noise ratio). The occurrence of the signal had to be precisely synchronous with that of the picture, so as to prevent attention being drawn to its location by its sudden onset during the time interval that the photograph was exposed.

3) The presentation of the pictures had to be smooth and uniform throughout the experiment in order to facilitate the normal vigilance decrement. 'Arousing' events such as overt irregularities of time periods of presentation of the pictures, or discontinuities in the expected visual patterns had to be avoided, as such events typically increase signal detection rates, at least for a short period of time after their occurrence (Broadbent, 1971). Such 'unexpected', or non-uniform visual aberrations had to be eliminated.

4) It was also considered necessary to remove any possible auditory cue, such as a 'click', associated with the presentation of a photograph, as, in the control condition, at least, this cue alone would enable the subject to respond 'correctly' to the presence of a picture without looking at it.

5) A method had to be devised for recording the subject's

responses both to the picture itself, and to the presence or absence of a signal within the picture. The resultant subject performance record could not be in the form of simple counters showing total correct responses to pictures, and the total number of successful detections of signals, because it was necessary to evaluate the time pattern of the distribution of errors over the testing session. For later analysis, it was necessary to know <u>when</u> errors or misses occurred, and the particular pictures or signals associated with them.

6) The subject had to indicate his decisions manually via a keyboard rather than vocalise them. The purpose of this requirement was to simplify the technical and practical problems of recording and analysis associated with 5), above. The subject had to make two 'yes-no' type decisions in response to every presentation of a picture. One decision was in relation to the identification of the particular photograph, and the second was with regard to the presence or absence of a signal within that picture. The requirement for two decisions at every presentation of a photograph provided a check that the subject was at least partially attending to the picture. If, for example, the subject had only to record a response if he thought a signal were present, it could not be determined unequivocally whether some detection failures were a result of not looking at the picture at all.

7) The duration of the experimental testing session had to be comparable with that associated with typical vigilance experiments, i.e. of at least one hour's duration. This requirement, together with the proposed 1 second picture exposure time and 5 second inter-stimulus interval, meant that the number of presentations of photographs to the subject

had to be at least 600 in a single testing session. This task specification, together with that of 6) above, meant that the event rate throughout the experiment was relatively high. However, existing research evidence suggests that the rate proposed (1 per 6 seconds) is unlikely to improve signal detection performance to any significant extent. (This work is cited and discussed at length by Broadbent (1971) p.35 and following). Even if the event rate chosen were to have any effect on signal detection rates, this effect would be exactly the same for both experimental and control groups. Thus, the performances achieved by both groups would be directly comparable.

To meet all the specifications listed above, the following apparatus and procedures were devised:-

The sequences of photographs were presented to the subject in black-and-white on a 585 cm screen Shibaden television monitor, by means of an IVC Model 601 videotape recorder. The specification of normal photographs as the complex visual patterns to be used in the experiment ruled out the use of any form of computer generated visual display.

The 'signal' was in the form of a small (0.8 cm dia), but clearly apparent 'blob' of white light, which could occur at any spatial position in any picture.

The photographs were recorded onto videotape by projecting them onto a white screen with a Kodak Carousel S slide projector. A Phillips television camera, equipped with a Monital zoom lens, was positioned directly above the slide projector and focused on the screen, so that the projected photograph filled the entire television screen. The projector was equipped with a solenoid operated shutter and an automated timing device which opened the shutter for 1 second at 5 second intervals. This 5 second interval was greater than the time period required for the operation of the automatic slide changing mechanism of the Carousel projector. Thus, while the shutter was closed, this mechanism could be actuated, changing the slide so that a new picture would appear on the screen when the shutter opened again.

When necessary, the signal was placed in the picture by means of a point source of light manually positioned against the back of the screen onto which the slide was projected. The presentation of the signal was exactly synchronised with that of the picture by means of a microswitch actuated by the shutter on the slide projector. The final form of the light signal such that 'halo' effects were eliminated, and the signal was always clearly visible, even in the 'white' parts of the photograph, was evolved by experimentation with a number of different bulb intensities, and the assistance of several observers.

By means of the above apparatus and methods, the necessary videotapes were recorded for both the experimental and control groups. The IVC videotape recorder had two auditory channels. Using an amplifier, a tone was recorded onto one of these channels each time a signal was embedded in a picture, this tone being initiated and synchronised with the signal by means of a microswitch attached to the shutter on the Kodak projector.

The subjects' responses to each picture were made using a keyboard consisting of 4 adjacent keys. One pair of keys was used by the subject for registering his decision with regard to the identification of the picture, and the other pair was used for registering his decision with regard to the presence or absence of a signal in the picture.

Each subject's responses over the entire testing session were recorded using 6 channels of a BRD, model ER8, 8 channel event recorder. Each key on the response keyboard was connected to one channel of the event recorder. As the videotape presenting the pictures to the subject was played back, the tones which had been recorded onto one auditory channel of the videotape recorder in synchrony with the occurrence of the signals, actuated an event on one channel of the event recorder by means of an amplifier. As a fail-safe precaution to allow for possible breakdown of the event recorder and to prevent the resultant complete loss of all the data, whenever the subject responded in the affirmative to the presence of a signal, a further tone was recorded onto the second auditory channel of the videotape recorder. In this way, if the event recorder failed during testing of a subject, it could be repaired and the videotape from that session played through again, and the subject's positive responses with regard to the presence of signals would be shown.

The final record of each subject's performance was in the form of a 6.5 cm wide pressure-sensitive paper tape, of 11 metres in length. The various responses of the subject, together with the record of the actual occurrence of the signals, were recorded in the appropriate channels as small step waves caused by deflection and return of each pressure stylus.

The duration of the main part of the testing session was determined by the length of the videotape, and was approximately 62 minutes for the experimental and control groups, being the maximum time that could be obtained with the IVC recorder used.

The pictures used in the experiment were in the 'normal' category described by Standing (1973). They were a varied collection of competent, heterogeneous photographs. From a pool of over 400 transparencies, 75 were finally chosen to be used in the experiment. These were subjectively equated for photographic quality by the experimenter and a second observer. A restriction on the use of certain photographs was imposed by the nature of the video-recording process. The necessary state of adjustment and lighting of the television recording equipment was highly sensitive to excessive changes in brightness and contrast from one photograph to the next. (This state of affairs effectively provided a form of objective control in relation to the variation of the photographs used).

For the purposes of the recording of the videotape to be used in the experimental group, the order of the 75 pictures was randomised in the projector carousel, and this sequence was recorded onto videotape using the procedure described above. After presentation of the 75 photographs the recording operation was stopped and the order of the 75 slides was again randomised. The new sequence was then recorded onto the videotape. This procedure was continued until the videotape expired, the signals being inserted in the pictures where appropriate throughout this recording process. During the recording of the testing tapes for both groups, whenever a signal was placed in a picture, if it were not clearly visible on the television monitor to the observers present during recording, the recording operation was stopped and that presentation was replaced by a satisfactory one. Finally, the completed tapes were checked in their entirety for picture and signal clarity, continuity, and electronic interference effects.

The distribution of signals over the time period of the experiments was close to that used by Mackworth (1950), approximately 12 to 13 signals being randomly distributed within the picture sequences in each 20 minutes. There was a total of 43 signals in the final tapes used for each group.

Because it was impossible to completely proof the testing room against the intrusion of some outside noise, a white noise generator emitted low intensity noise through headphones worn by the subject for the duration of the vigilance task.

During the vigilance task, each subject was alone in the experimental room. The presence of additional persons in the room in such task situations has been shown to increase signal detection rates (Broadbent, 1971). However, observational checks on both apparatus and subject could be made by the experimenter from an adjacent control room through a one-way mirror. At no time were subjects aware that they were under observation, the curtains over the mirror being drawn, leaving just sufficient visibility necessary for the experimenter's purpose. From the seated position of the subjects, the curtains appeared fully closed.

The experimental room was lit by soft, low intensity indirect light to prevent eyestrain.

(ii) <u>Subjects</u>

20 undergraduate and postgraduate students of the University of St. Andrews (10 male; 10 female) participated in the experiment. All had normal corrected vision and no optical defects. A further 10 such subjects had previously assisted in various pilot studies connected with the extensive operational development and reliability testing of the equipment and methods. None of these earlier subjects were used in the main experiment. All subjects were unpaid volunteers.

(iii) Procedure

Subjects were seated at a table on which was situated the response keyboard. Seating and keyboard positions were adjusted to suit the comfort of the individual subject. Where appropriate, the subject's watch was removed. The television screen on which the stimulus pictures would appear was positioned directly in front of the subject, at a distance of approximately 2.4 metres from his eyes, with the centre of the television screen approximately at the subject's eye level.

The experimental procedure was then as follows:-

I Control Group

Subjects were first shown on the television screen a series of five 5-second exposures of the single photograph to be used throughout the experiment. The subjects were instructed to memorise the photograph.

It was then explained to the subjects that, during the main part of the experiment, a signal would occasionally be present at some random position within the photograph. A number of further presentations of the photograph were then made, this time with each one containing a signal in a different spatial position. The purpose of this series of exposures was to thoroughly familiarise the subject with the nature of the signal, and to check that the signals were clearly visible to the subject. The stop-motion facility on the IVC videotape recorder was of considerable assistance in this part of the procedure.

The method of response using the keyboard was then explained to the subject, a diagram of the keyboard layout is shown in Fig. 8 . The two left-hand keys were concerned with response to the identification of the picture. Each time a picture was presented in the experiment, if the subject identified it as one which he had been instructed to memorise earlier, he pressed the 'picture-same' key. If the picture was not one memorised earlier, the subject pressed the 'picture-different' key. In the case of the control group, the picture shown at each presentation was always the same as the one memorised earlier. If the subject perceived the presence of a signal in the picture, he pressed the 'signal present-yes' key. If he did not perceive a signal, he pressed the 'signal present-no' key. Thus, at every occurrence of a picture, the subject always had to press two keys.

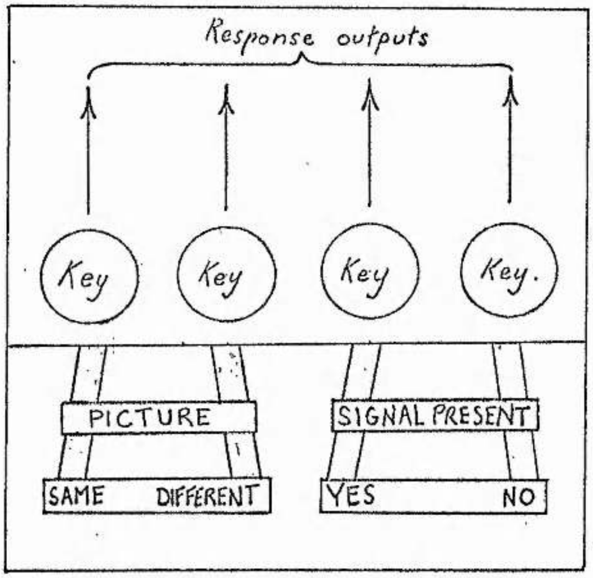

Fig.8 : Plan of response keyboard

Next, the subject was shown a series of exposures of the picture at the presentation rate and exposure time to be used in the main part of the experiment. Some of these pictures contained a signal, and some did not. For this practice series of presentations, the subject was asked to respond using the keyboard, according to the instructions given. After several such practice runs, when it was clear to the experimenter that the subject was fully conversant with the experimental procedure and responding satisfactorily, and that the apparatus was fully serviceable, the main part of the testing session commenced.

For the vigilance task, the instructions to the control group subjects were as follows:-

"In the next part of the experiment, the picture you have memorised will be presented to you on the screen a very large number of times. Each time the picture occurs, you must respond using the keys in the way you have been shown. Now, I can tell you that it will always be exactly the same picture at every presentation for the entire period of the experiment. There are no 'different' pictures included to try to catch you out. However, you must respond 'picture-same' at every presentation.

Occasionally, a signal exactly like the ones you have been shown will be present in the picture. It will always be clearly visible. However, the occurrence of these signals will be, on the whole, fairly infrequent, and completely at random. A signal can occur at any presentation and it can be at any position in the picture. Remember that you must make a 'yes' or a 'no' response about the presence of a signal every time the picture is presented.

So, in this experiment, your task is to identify the picture correctly each time it occurs and to detect as many signals as you possibly can. You may press the response keys in any order you wish on each presentation. Rapid reaction time is not important in this experiment; respond reasonably quickly, but be as accurate as you can. Remember you have five seconds between pictures. If you think you have pressed the wrong key, you may change your mind and quickly press the correct one. I will consider your final decisions for each picture as your responses to that picture.

Now, sometimes a signal may become present in the blank spaces between pictures. In this case, press the 'signal present-yes' key only. You must try and keep your attention focused on the screen all the time.

I will ask you to put the headphones on in a moment. These have a low intensity 'hiss' coming through them to mask any possible distracting noises. I will leave this room once I have started the apparatus and return when the experiment is over. Do you have any questions? Remember, you must press <u>two</u> keys after <u>every</u> picture, one relevant to the picture and one relevant to the signal."

After placing and adjusting the headphones on the subject, the experimenter left the testing room. At subsequent frequent intervals during the testing period, the experimenter checked the progress of the subject and the performance of the apparatus through the one-way mirror.

Although no signals were ever present on the television screen in any interval between pictures, the instructions to subjects suggested that there might be in order to maintain, as far as possible, the attention of the subject focused on the potential signal source, and its immediate visual environment, throughout the experiment.

On completion of the session, the experimenter returned to the testing room. Subjects were then interviewed and invited to comment on any aspect of the experiment. The experimenter questioned subjects with regard to their ability to maintain concentration on the task, the monotony or boredom of the task situation, and what happened when their concentration lapsed, i.e. whether they started thinking about other things during task performance. Finally, a brief explanation of the experimental aims was given to the subject.

II Experimental group.

Subjects in this group were first shown on the television screen a series of 15 heterogeneous 'normal' photographs, each being presented for a 5 second exposure time. This series was then shown again in the reverse order at the same 5 second item exposure time, and finally, the series was presented a third time, each picture being exposed for 5 seconds. Thus, each picture was seen by the subject for a total time of 15 seconds. Prior to the showing of this set of pictures, the subject was instructed to commit them to memory. The extremely accurate remembering of such a relatively small set of heterogeneous pictures presents no problems to subjects (see Chapters IV and V).

It was then explained to the subjects that a signal might sometimes be present in the pictures, and a series made up of all the pictures the subject had memorised was shown, each one containing a signal embedded within it at some random position. The purpose of this procedure was to familiarise the subject with the nature of the signal and to check that all the signals were clearly visible to the subject. As for the control group, the stop-motion facility of the videotape recorder was of considerable assistance in this respect.

The response procedure using the keyboard was then explained to the subject, as for the control group. Next, the subject was shown a series of pictures consisting of some from the set memorised earlier, and some not previously seen by the subject. A number of these pictures contained signals, and the series was presented at the same event rate and exposure times to be used in the main part of the experiment. For this practice series, the subject was instructed to respond to each picture presentation using the keys in the manner in which he had been instructed. After several practice runs through this series, when it was clearly apparent to the experimenter that the subject fully understood the experimental procedure and was responding satisfactorily, and that the apparatus was functioning correctly, the main part of the testing session was commenced.

For the vigilance task, the instructions to the experimental group subjects were as follows:-

"In the next part of the experiment a very large number of pictures are going to be presented on the television screen, one after the other, in the same manner as those you have just seen in the practice run. Some of the pictures will be the same as the 15 you have memorised, and many will be different. Each time a picture is shown you must respond using the keys in the manner you have been shown and which you have just practised. Remember, if the picture is the same as one you have memorised, press the 'picture-same' key, and if it is not one you have memorised, press the 'picture-different' key. You must make a decision like this for <u>every</u> picture presented. Now, because the experiment goes on for quite a long time, even though there is a large number of pictures, you will eventually see them all more than once. So, always remember that you press the 'picture-same' key only when the picture presented is one of the set of 15 you have memorised already, even if the particular picture may have occurred before in the experiment. Is that clear? The same-different category refers only to the 15 pictures you have already memorised.

Occasionally, a signal exactly like the ones you have been shown will be present in the picture. It will always be clearly visible. However, the occurrence of these signals will be, on the whole, fairly infrequent, and completely at random. A signal can occur at any presentation, and it can be at any position in the picture. Remember that you must make a 'yes' or a 'no' response about the presence of a signal every time a picture is presented."

The remaining instructions and testing procedure for the experimental group subjects were exactly the same as for the control group.

6.4 Results and discussion.

(i) Method of analysis of the raw data.

Each of the paper tapes forming the record of a subject's performance was analysed and cross-checked in the following manner:-

(a) Each event on the tape was numbered and the total checked with the actual number of picture presentations for the group (= 618 for the control group, and 624 for the experimental group). During this exercise of numbering, it was clear from discrepancies in the size of the normally regular interval between responses when the subject had failed to respond to a picture presented.

(b) The occurrence of each signal presented to the subject was numbered, and this total checked against the correct total (= 43). As a further cross check, the number of each signal was compared with the corresponding picture presentation number.

(c) A subject's affirmative response to the occurrence of a signal was shown in the two channels adjacent to that indicating the actual presence of a signal. (One of these two channels indicated that a tone had been recorded onto the second auditory channel of the videotape recorder, for the reasons outlined earlier (p.161)). Scores for the total number of signals detected and the total number of signals missed were thus ascertained, together with the actual signal and event numbers associated with each detection failure.

(d) False alarms were scored by careful and repeated visual inspection of the tape. In this way total numbers of false alarms were obtained as well as the actual picture presentation numbers associated with each false alarm.

(e) The picture identification responses were scored using a master reference table showing each event number and the correct picture response associated with it. This table also indicated the actual picture shown at every presentation.

(f) Where a subject changed his decision on any presentation, the two final responses for that event were taken to represent the subject's definitive responses to that presentation.

Because of the considerable length of the paper tapes, each of which recorded over 1200 decisions for every subject, each complete tape was carefully checked for scoring accuracy a minimum of four separate times.

(ii) Signal detection results.

The total number of signals missed and the total number of false alarms for each subject in the control group are shown in table XVI. Table XVII shows these results for the experimental group.

The difference between the mean number of signal detection failures for subjects in the experimental group and the mean number of signal detection failures for subjects in the control group was significant at the 0.002 level on a two-tailed 't' test. ($t = 4.42$; 18 degrees of freedom), the variances of this parameter for the two groups being

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TABLE XVI

Signal detection performance: control group.

Subject	Sex	Total no. signals missed	Total no. false alarms
AC	F	7	1
CG	F	7	4
PR	F	5	3
DC	F	10	11
MF	F	11	1
JM	M	10	0
RH	M	7	0
PB	M	9	0
HE	M	4	0
AM	M	6	4
Mean/S.D.		7.6 / 2.20	2.4 / 3.26

Notes (i) No subject failed to respond at any presentation.

(ii) There were no significant sex differences in no. of signals missed ($t = 0.52$; 8 d.f.), or number of false alarms ($t = 1.59$; 8 d.f.)

TABLE XVII

Signal detection performance: experimental group.

Subject	Sex	Total no. signals missed	Total no. false alarms
JGr	F	2	3
AC	F	2	7
AS	F	3	18
K	F	6	4
JW	F	1	1
JWr	M	7	32
IA	M	5	11
BC	M	2	2
JG	M	0	3
BM	M	3	18
Mean/S.D.		3.1 / 2.11	9.9 / 9.49

Notes (i) No subject failed to respond at any presentation.

(ii) There were no significant sex differences in no. of signals missed ($t = 0.40$; 8 d.f.), or number of false alarms ($t = 1.04$; 8 d.f.)

homogeneous. ($F = 1.08$; $V_1 = 9$, $V_2 = 9$) The mean number of signals missed by the control group (= 7.6) was over twice as great as the mean number of signals missed by the experimental group (= 3.1). This empirical result very strongly supports the two main predictions derived from the present theory.

Firstly, the prediction that there would be a decrement in signal detection performance in the single complex pattern condition was confirmed, subjects in the control group failing to detect 17.67% of the signals. Secondly, the theoretical prediction that subjects in the multiple complex pattern condition would detect more signals than those in the single pattern condition was confirmed, the empirical differences in signal detection performance between the two groups being in the direction predicted, and highly significant statistically. Subjects in the experimental group failed to detect only a mean of 7.2% of the signals.

The false alarm rates of subjects show that there were more false alarms associated with the experimental group. However, the variance in the experimental group was substantially increased by the relatively high false alarm rates of three subjects, one of whom scored 32 false alarms. If the results of these three subjects are disregarded, the difference between the false alarm rates of the two groups is not significant ($t = 1.19$; 15 degrees of freedom), although the mean number of false alarms for the experimental group is still higher than that for the control group. The higher false alarm rate of the experimental group supports the notion that the visual signal to noise ratios associated with the larger number of pictures were effectively lower than those associated with the single picture condition of the control group.

The experimental group subjects, in addition to overlearning the 15 stimulus pictures, also saw the signal at least 20 times prior to commencement of the main vigilance task. Consequently, the overlearning of the visual appearance of the signal, combined with the 'noisier' pictures and the varying degrees of subjective probability of occurrence of a signal at each event may well have facilitated the subject's perceptual experience of a signal which was not in fact present. This explanation is in accordance with the present theory in that information held in memory concerning the physical appearance of a signal may be incorporated into perception of a picture.

There is an alternative explanation of the higher false alarm rates of the experimental group, based on signal detection theory. According to this argument, subjects in the experimental group were altering their criteria of sensitivity in order to be more certain of not missing a signal if one were actually present. This response strategy would result in an increase in the false alarm rate. However, such an explanation is not consistent with a more detailed analysis of the data. If this explanation were correct, high false alarm rates should be associated with high rates of signal detection - i.e. there should be some degree of positive correlation between the number of false alarms and the number of signals detected by each subject. This should be the case for both experimental and control groups. However, it was not, the product-moment correlation coefficient between number of signals detected missed and number of false alarms being r = - 0.1 for the control group, and r = - 0.6 for the experimental group. Although the absolute value of this correlation for the experimental group is rather high, it is in precisely the <u>opposite</u> direction to that predicted by the sensitivity explanation. If the results of the single subject who scored 32 false alarms are disregarded, the correlation drops to r = - 0.3.

The above analysis shows clearly that the experimental group subjects were not detecting more signals simply because their false alarm rate was higher. Even the maximum number of false alarms achieved by any subject represented only one false alarm per 20 presentations. The equivalent mean figures were a false alarm rate of 1 every 257 events for the control group, and 1 every 62.4 events for the experimental group (= 1 every 141 events if the three anomalous results are disregarded).

In the case of the experimental group, detailed analysis of the patterns of each subject's false alarms in terms of the actual picture presentations and specific pictures with which they were associated reveals the primary reason for the greater number of false alarms in the experimental group.

The set of pictures used in the experimental group consisted of 75 photographs. This meant that, because of the extended time duration of the experiment, which allowed 624 presentations, each of the photographs in the set was seen by the subject at least 8 times during the experiment. Consequently, if at the beginning of the testing session, a subject positively interpreted some thing in a particular picture as a signal, even though there was no actual signal present, he was likely to tend to make the same error on each subsequent occurrence of that picture for the remainder of the experiment. Thus, for example, subject JWr scored 32 false alarms, but these were accounted for by only 14 different pictures. Table XVIII shows, for the experimental group, the total number of false alarms made by each subject, together with the total number of different pictures associated with those false alarms.

From this analysis, it is clear that the increased false alarm rate of the experimental group was primarily an artifact of the large number of pictures used compared to the single picture of the control group. The distribution of a considerable proportion of the false alarms was non-random and generally associated with the repeated occurrence of specific pictures.

The very low overall false alarm rates and the consistent distribution patterns of occurrence of many false alarms indicate that subjects in both groups were performing according to their perceptual experience of the photographs at each presentation rather than guessing the occurrence of signals.

TABLE XVIII

False alarm analysis: experimental group.

Subject	Total no. of false alarms	Total no. of different pictures associated with these false alarms
JGr	3	3
AC	7	6
AS	18	15
K	4	4
JW	1	1
JWr	32	14
IA	11	9
BC	2	2
JG	3	2
BM	18	8

(iii) Picture identification results

(a) Control group

All the subjects in the control group correctly responded 'picture-same' to all 618 presentations of the single picture used in the control situation. This result, together with the low false alarm rate and the fact that no control subject failed to make either a 'yes' or a 'no' response regarding the presence of a signal on any presentation, is strong evidence that, at each presentation all subjects were at least partially attending to the television screen.

(b) Experimental group

Picture identification errors for the experimental group are shown in table XIX.

TABLE XIX

Picture identification errors: experimental group

Subject	Errors
JGr	0
AC	0
AS	0
K	13
JW	0
JWr	0
IA	18
BC	0 *
JG	0 *
BM	3

* Complete record not available because of mechanical failure of event recorder.

Picture identification performance of all subjects in this group was extremely good, 5 subjects making no errors at all over the 624 randomly ordered presentations. In the cases of those subjects who did make some errors, detailed analysis of the records showed that for each of these subjects, most of their errors were associated with particular pictures. That is, if, at the beginning of the experiment, a subject incorrectly classified a picture as either being or not being one of the 15 memorised prior to the experiment, this incorrect decision was repeated on the majority of times that picture occurred during the experiment. In the case of subject I.A., two particular photographs accounted for 11 of his 18 errors, and for subject K., two specific photographs accounted for 10 of her 13 errors. Failure of the event recorder during testing of subjects BC and JG meant that completed records of picture identification performance were not obtained for these subjects. However, neither of these subjects had made any errors up to the time at which the event recorder failed, this failure occurring after approximately ½ to ⅔ of the total testing session time had elapsed.

The nearly error-free performance on the part of the experimental group subjects is empirical evidence that an important aim of the experimental design strategy was achieved. Because of the complete unpredictability of the random sequence of pictures throughout the experiment, the very high proportion of correct responses shows that, at each presentation subjects were attending to and processing at least sufficient proportions of visual sensory information referent to the picture to enable them to accurately discriminate between the 75 pictures.

(iv) Further analysis of signal detection failures.

Fig. 9 graphs the total numbers of detection failures made by all subjects on each individual signal for the control group. Fig. 10 illustrates the actual distribution of signal detection failures for each of the control group subjects. Figs. 11 and 12 show the equivalent results for the experimental group.

This analysis shows that most control subjects missed signals 18, 19 and 26. For some reason these signals were not detected by the majority of subjects, although signal no. 18 was the only signal missed by all subjects.

Prior to commencement of discussion of this point, it should be emphasised that if signal 18 is entirely eliminated from the scoring of signal detection failures of all control subjects, the difference between the new mean number of signals missed by the control group subjects (mean = 6.6; SD = 2.2)

Results: Vigilance experiment - Control group.

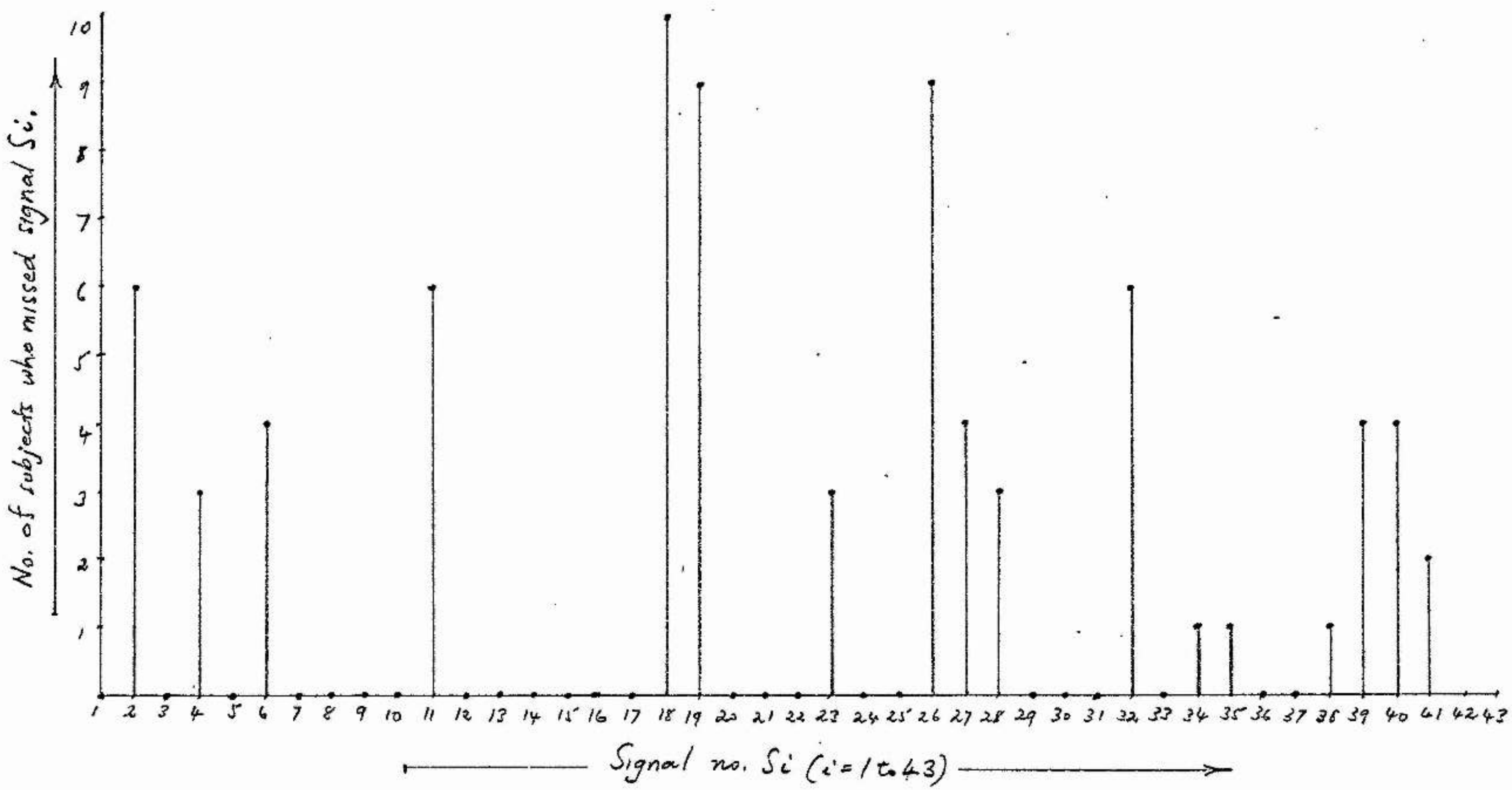
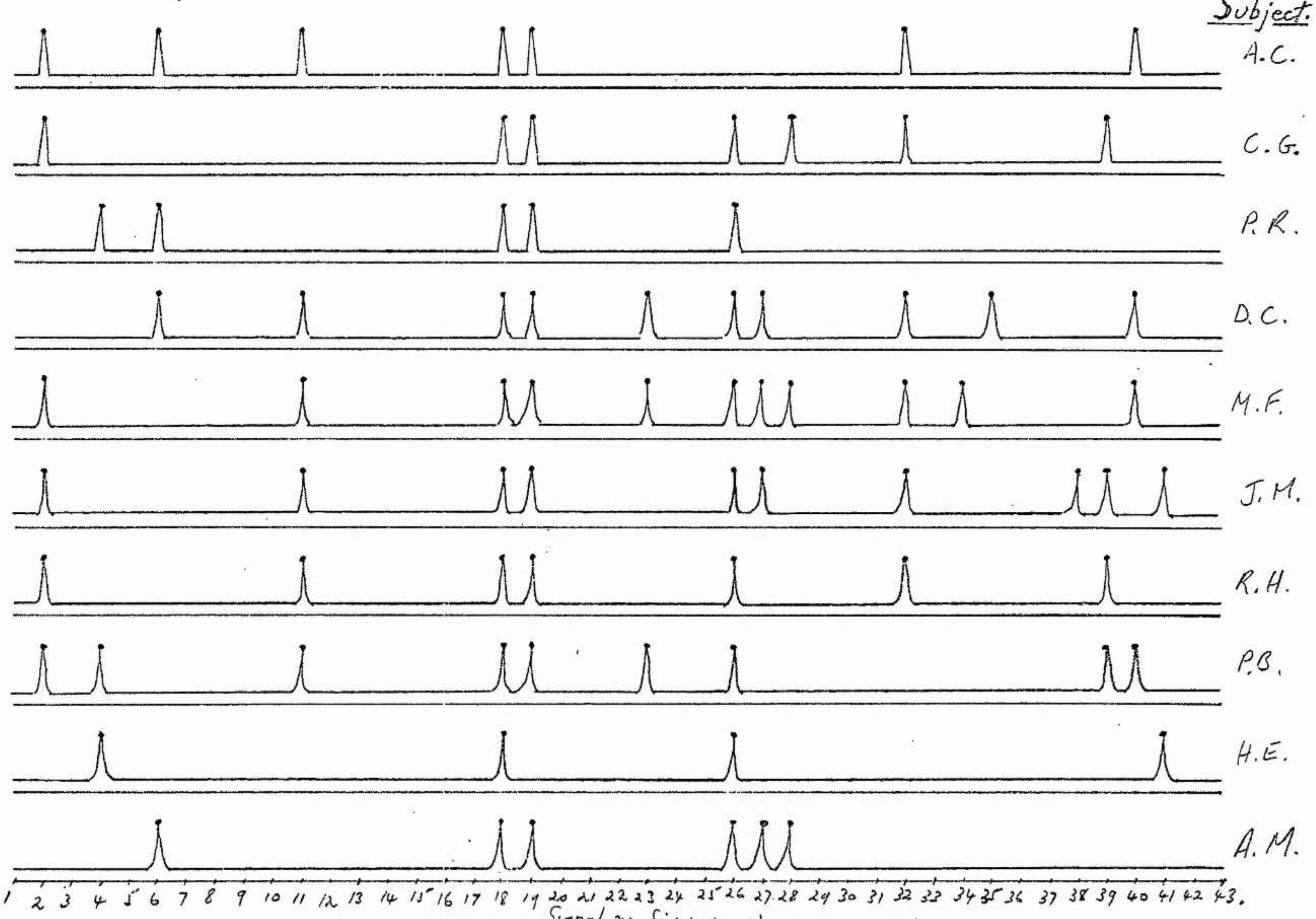


Fig 9.



Individual signal detection failures - Control group.

Fig. 10.

Results – Vigilance experiment – Experimental group.

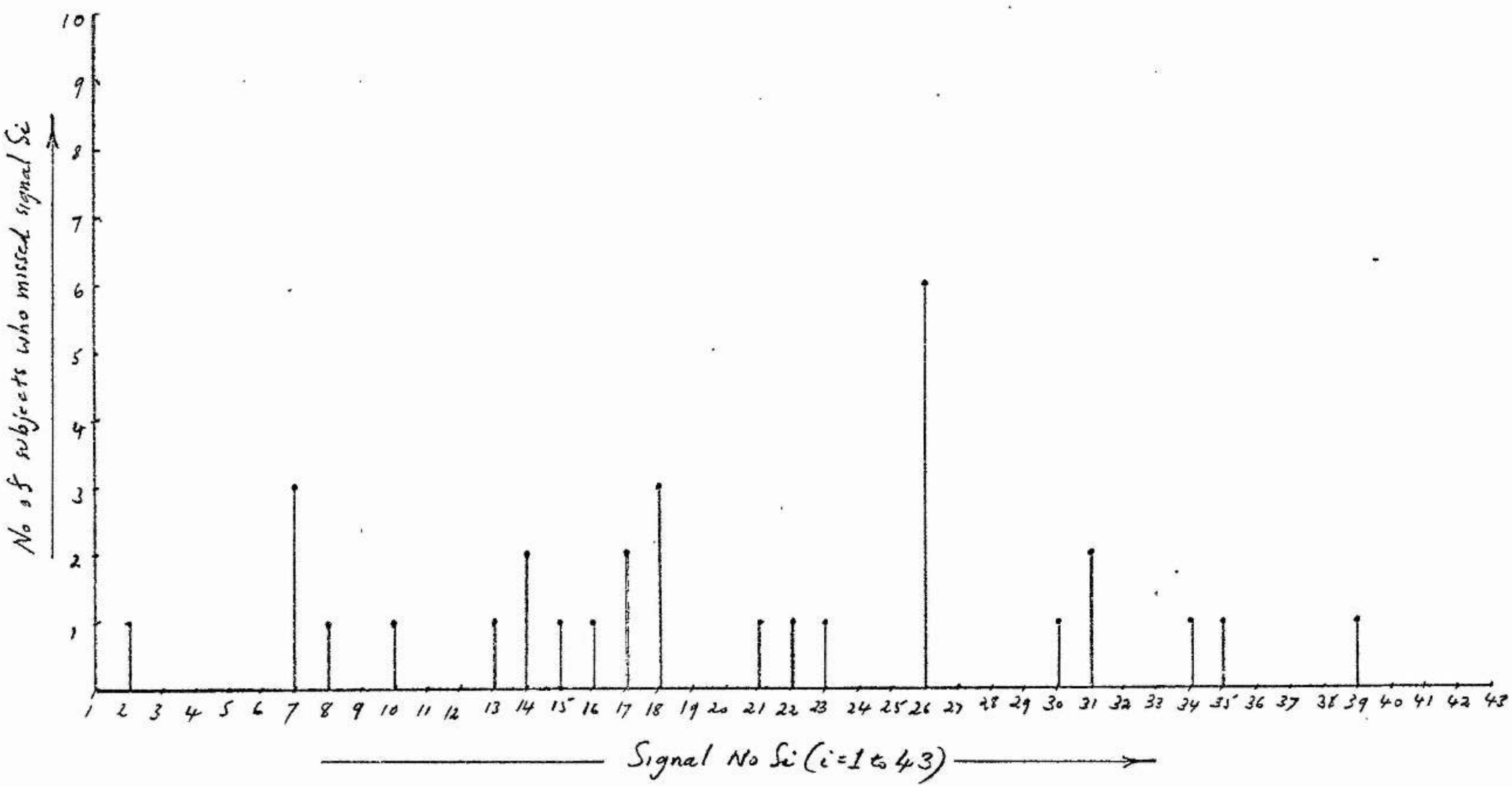
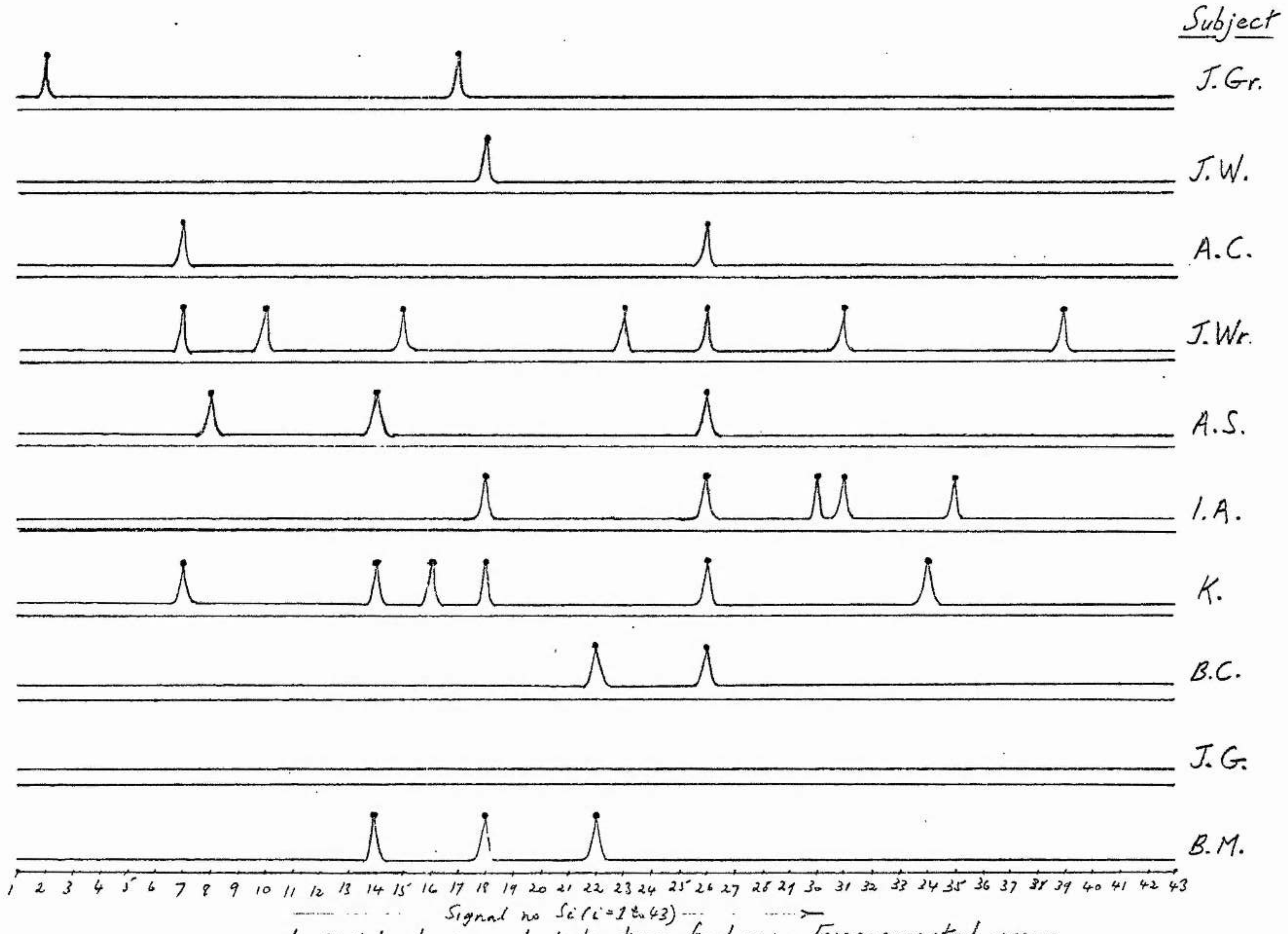


Fig. 11.



Individual signal detection failures – Experimental group.

Fig. 12.

and the mean number of signals missed by the experimental group subjects (mean = 3.1; SD = 2.11) remains significant at the 0.01 level on a two-tailed test (t = 3.43; 18 degrees of freedom).

In order to determine whether the failures to detect these particular signals were simply a result of the signals being difficult to see, which was highly unlikely in view of the way in which the tapes were checked during recording, a small experiment was carried out. For each of the three contentious signals, separate sets of 5 subjects who had not participated in the main experiment were obtained. Each of these subjects was individually taken into the experimental room and seated in the position occupied by subjects in the vigilance experiment. The nature of the signal was described verbally to the subject, and the videotape used for the control group was started several events prior to the occurrence of the particular signal under consideration (i.e. 18, 19, or 26), the subject was instructed to say 'yes' when he saw a signal somewhere in the picture on any occurrence. None of the subjects employed in this small experiment had actually seen a signal prior to its occurrence in the picture, and could therefore not be entirely certain of what to look for. However, all responded correctly to the presence of the three signals (i.e. 5 subjects for each signal). Clearly then, detection failures in relation to these signals could not be attributed to a straightforward problem of visual discrimination associated with these signals.* On this point it should again be noted that the occurrence of a signal was exactly synchronous with that of the picture, i.e. it was present on the screen for a full second.

Prior to the occurrence of signal 18 there were 32 presentations which did not contain a signal, and signal 19

* A photograph of signal 18, showing that it was clearly visible is included in Appendix IV.

followed only 18 events later. Signal 20 followed 11 events after signal 19; signal 21, 16 events after signal 20; and signal 22, 7 events after signal 21. No subjects missed signals 20, 21 and 22. For signal 26, 15 presentations which did not contain signals occurred before it. Overall, for the control group there was only the slightest tendency for a greater number of signal detection failures to be associated with longer time intervals prior to their occurrence ($r = 0.24$)

Although 17 signals of the 43 shown accounted for all the signal detection failures in the control group, the mean number of misses for the group was less than half this figure. ($= 7.6$). This shows that detection failures were distributed across all these signals, some subjects detecting particular signals which other subjects missed. However, these other subjects may have detected some signals which the first group missed, and so on. The varied patterns of detection failures, although restricted to 17 signals, shows clearly that misses were not due to the signals being difficult to discriminate visually.

If the total numbers of signal detection failures for each one third of the time duration of the experiment is plotted for both experimental and control groups, it can be seen that many more detection failures occurred in the middle 20 minutes of the experiment than in either the first or last 20 minute periods, there being little difference between the number of detection failures for these two periods. (Fig. 13.).

It seems clear from these results that the explanation of the pattern of missed signals, a pattern which was similar for both groups, is that, in general, subjects' attention to the task tended to lapse more in the middle of the experiment, leading to greater numbers of detection failures in this time period.

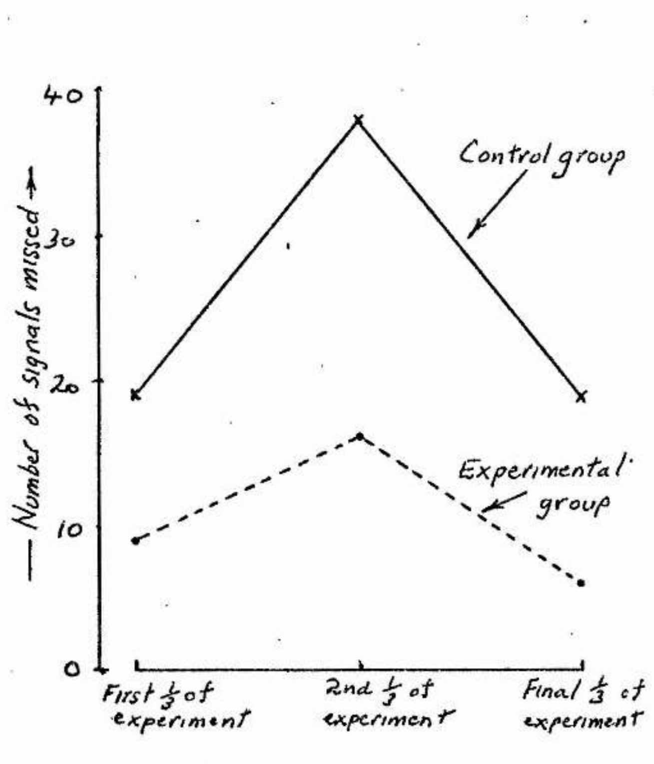


Fig. 13.

When attention lapses, the present theory proposes that a lesser proportion of real visual sensory information is processed, resulting in a reduction in the probability that a signal will be detected (see p. 152). The results for the control group showed that all subjects responded to every presentation of a picture throughout the experiment. These presentations were not accompanied by any auditory cues. Consequently, it can be presumed that all the control subjects were processing at least some proportion of visual sensory information referent to the pattern at each presentation. On many presentations this proportion of sensory information was the minimum necessary to confirm the presence of the pattern expected. It is proposed that the reason that certain signals tended to be associated with a greater number of detection failures than others, particularly when attention had lapsed, was not that these signals were difficult to discriminate visually, but rather that they were positioned in what may be termed low-priority information areas.

Under conditions where only partial attention is devoted to pattern recognition, the proportion of real visual sensory information, referent to an overlearned pattern, which is processed is reduced. It is proposed that this reduction is selective in the sense that the reduced proportion of sensory information is referent to the minimum number of fundamental semantic characteristics subjectively considered necessary to identify the particular expected overlearned pattern. Thus, real visual sensory information which is redundant with reference to this purpose will be less likely to be processed when minimum capacity is dedicated to the identification of the pattern. In general terms, the notion is that, when the available pattern processing capacity is reduced, redundant visual sensory information is less likely to be processed. The processing of this redundant information is of low priority in the identification of the expected complex pattern. The subject consciously experiences perception of the complete pattern, the necessary redundant proportions of information come from the memory store.

On the basis of this argument, the reason that certain signals were detected less often than others was that they were positioned in areas of redundant information. Thus, under conditions of partial attention the essential picture defining sensory information processed from the pattern did not contain these signals, and they were therefore not detected. Where the signals tended to be positioned within non-redundant information areas, they would tend to be detected, even under conditions in which only part of the subject's capacity was dedicated to the

the control group than in the experimental group. In the latter group, the missed signals were distributed across a wider range of signals. At every event in the experimental group, the requirements of the picture identification task caused more real sensory information from each picture to be processed. When attention lapsed, the proportion of real sensory information necessary to accurately perform this identification task was reduced to a minimum. Consequently, signals in low priority information areas would tend to be missed. However, the wide range of photographs with their varying degrees of interest or familiarity between individual subjects can be assumed to have contributed to substantial individual differences in picture processing strategies with respect to many of the photographs used. This resulted in a greater variance with regard to what constituted low priority information areas within each picture. Thus, although more signals were missed by the experimental group in the middle period of the experiment because attention had lapsed, just as for the control group, these detection failures tended to be distributed over a somewhat greater number of pictures. However, although the pattern of signal detection performance over the duration of the task was the same for both the experimental and control groups, the detection performance of the experimental group was always superior, even when processing of sensory information from the pattern. When maximum capacity is dedicated to processing of the sensory information from the pattern, the redundant, or low priority information areas are included, and any signals are more likely to be detected.

Note that the term "redundant information" in the present context is quite specifically related to the extent to which that portion of information is subjectively considered necessary to the correct identification of a particular expected overlearned pattern. The specific proportions of pattern information which are considered "redundant" <u>with respect to this purpose</u> may vary within subjects over different presentations of the same pattern, and between subjects in relation to the same patterns. The concept of 'redundancy' as used in the present context is not necessarily linked directly and unambiguously to specific physical properties of a stimulus pattern (e.g. homogeneity); rather, it refers to the semantic characteristics of the various areas of information in the pattern. Thus, for example, a particular visual feature of some kind in a pattern may be 'redundant' (i.e. of low priority in identifying that picture) to one subject who may not be interested in that specific feature of the pattern, but the same feature may not represent redundant information to another subject, whose interests in the same pattern may be quite different to those of the first subject.

The preceeding argument also explains why larger numbers of detection failures were associated with <u>particular</u> signals in attention had lapsed. This was because performance of the associated picture identification task caused a greater proportion of visual sensory information to be processed at each picture presentation.

The preceeding discussion and the experimental techniques developed in the present study suggest a method by which probe signals may be used, in situations where subjects are required to recognise overlearned complex visual patterns under conditions of partial attention, to define the low priority information areas of these patterns. Such a technique may well be useful in the research area of feature analysis.

(v) Evaluation of interview data.

When interviewed after the completion of the vigilance testing session, all subjects in the control group stated that they found the task monotonous, and that, as a result they found it difficult to sustain full and continuous concentration on the task. All reported that, as a result, for periods during the experiment they started 'thinking about other things'. This introspective information was extremely important as it showed that a fundamental aim of the experimental design strategy was achieved. (No control subjects expressed any desire to repeat their experience).

In contrast, subjects in the experimental group found the task somewhat more interesting, although, many reported that, at times they felt that they were not concentrating as much as they could have done. During these periods they, too, found themselves 'thinking about something else'.

The subjects in the experiment all performed extremely conscientiously, and were obviously well motivated to perform to the best of their abilities. Clear evidence of this is that the proportion of responses on which subjects changed their initial decision with regard to either signal detection and/or picture identification was negligible for all subjects in both groups.

(vi) Consideration of an alternative interpretation of the experiment.

Before concluding the report of this experiment, an alternative interpretation based on signal detection theory will be briefly considered. It was suggested earlier that the 'visual signal-to-noise ratio' for the single picture situation of the control group would be greater than that for the experimental group where a large number of pictures were used. In the case of the experimental group, the large number of photographs would have the effect of decreasing the visual signal to noise ratio. With the constant repeated exposure of the identical picture in the control group situation, and the associated gross overlearning of that picture, fine differences in the picture, and certainly differences as obvious as the presence of a signal, should therefore be more easily detected. On the basis of this analysis of the experiment, subjects in the control group should have performed better than, or at least as well as, subjects in the experimental group. However, this was not the case.

(vii) A note on 'arousal'.

Despite a great deal of research effort, precise definition of the concept of arousal, and the nature of its role in relation to performance in vigilance task situations, remains undetermined, with much relevant research evidence in conflict over apparently fundamental issues. Broadbent (1971, p.45-51) discusses at length the history and present state of the arousal approach to vigilance, and concludes as follows: "In summary of the arousal approach ... we must accept that some general state of the man, raised by stimulation having nothing to do with the task can affect efficiency .... Low arousal certainly means poor performance, but high arousal does not necessarily mean either good or bad performance" (ibid., p.51).

In the present context, it is considered that the concept of arousal is not sufficiently clear to facilitate its meaningful application to the experiment reported in this chapter. However, some comments on this point will be made.

It might be argued that the experimental group in the present study detected more signals because their level of arousal was generally greater than that of the subjects in the control group. However, in both groups subjects were making two responses every 6 seconds to events occurring on the television screen. No subject in either group failed to make the two required responses at any presentation. Thus, subjects in both groups were maintaining the same level of 'arousing' activity throughout the experiment.

Even if we therefore assume that both groups were, in general, equally aroused, then the observed performance differences may be readily explained in terms of the different proportions of cognitive processing capacity dedicated to the task by subjects in the two groups. It is proposed that subjects in this, and many other vigilance experiments, failed to detect signals, not through any reduction in the level of arousal, whatever that may be, but because of an internalised redistribution of the relative proportions of their cognitive processing capacities dedicated to performance of the vigilance task and to the performance of internalised thinking. Thus, if we consider the problem in terms of a concept of 'cognitive arousal', a subject in a vigilance task who misses signals because his attention to the monotonous task lapses and he starts daydreaming, for example, is just as cognitively aroused as a subject who is dedicating all of his cognitive processing capacity to the performance of the vigilance task. However, the second subject is likely to detect more signals than the first because a greater proportion of his available processing capacity is dedicated to the analysis of real visual sensory information referent to the vigilance task.

6.5 Conclusions

The experiment reported in this chapter was quite different in nature to those described in preceeding chapters of this thesis. However, once again, the fundamental concepts of the theoretical approach developed earlier were strongly supported by the empirical results obtained. The experiment was devised on the basis of the application of the present theory to a consideration of vigilance phenomena. Quite specific results were predicted by this theory, which were in contrast to the different predictions derived from some other, more traditional, theories associated with vigilance. The results of the experiment were most parsimoniously interpreted in terms of the theoretical approach of the present thesis.

To the writer's knowledge, no previous experiment has considered the concept of vigilance in this particular way, nor has any previous experiment investigated sustained picture identification performance in a similar manner. In the present experiment a total of almost 25000 subjects' decisions were analysed.

New experimental techniques were devised which may well be relevant to the investigation of other areas (e.g. feature analysis). It is hoped that the difficult and time consuming technical problems associated with the new experimental procedures devised can be substantially reduced, and that various refinements of control can be incorporated into future experiments, such as the use of over 600 different pictures, rather than 75, to prevent recurrence of pictures throughout the experiment. Also, it would be useful to devise a relatively inexpensive practical way of continuously presenting pictures for up to 2 to 3 hours, rather than the 1 hour of the present study. The application of the theoretical concepts and empirical findings of this experiment to the cognitive processing problems of the human operator in complex man-machine systems will be discussed in the final chapter of this thesis.

Chapter VII

7.1 This chapter discusses and describes the development of a computer simulation technique which incorporates fundamental concepts of the theoretical approach of the thesis.

7.2 Prior to the description of these computer simulation procedures, it is necessary to specify the purpose of using such methods in the present context, and the validity of their application to actual experimental situations. Firstly, it should be made clear that the simulation to be described is not concerned with the controversial area of 'artificial intelligence' (e.g. Turing, 1950; Newell and Simon, 1972). The computer in the present case is not being utilised to find detailed algorithms for human behaviour in a particular situation. The intention was not to evolve a program of the sort which purports to 'think like a man'. The purpose of the simulation to be reported in this chapter was of a primarily descriptive and illustrative nature. The aim was to apply qualitative theoretical concepts to a particular situation, and to determine what kind of performance might be achieved in this situation by a hypothetical system incorporating these basic concepts. The simulation model of behaviour was intentionally not of the over-ambitious and elaborate type criticised by Broadbent (1971), and its interpretation is not ambiguous.

Although intended to embody and illustrate quite general principles, the scope of the program was deliberately restricted to the broad problem of what sort of global performance a given system might achieve, rather than the specific problem of the detailed elaboration of the nature of the information processing methods by means of which it achieves this performance. In computing terms, the simulation is concerned more with the concepts, or general principles, on the basis of which a program (or several programs) may be written, than with the details of the program itself. There are often considerable differences between a number of computer programs written to fulfil basically the same purpose.

If the resulting simulation program can readily be made to achieve performances closely analogous to those actually achieved by human subjects, without the excessive employment of arbitrary artifact, and if some degree of quantification is embodied in the program regarding a parameter which may not be directly observable in the real situation (e.g. 'per cent of total attention'), then there may be some justifiable basis for making general inferences with reference to the quantification of that parameter in the real subject. This is especially so if the fundamental basis of the simulation is purely theoretical and is not derived 'ad hoc', or 'post hoc', from the particular situation which it is intended to simulate.

7.3 It is intended that the simulation techniques developed and demonstrated in this chapter should be considered as a potentially useful aid to the understanding of the areas of behaviour with which the present theoretical and experimental research is concerned.

It is strongtly emphasised that the simulation technique to be described is intended only as a heuristic device which may provide a useful practical aid to the understanding and investigation of human cognitive processing performance. The simulation program should be regarded as a research tool to be used by the investigator in conjunction with both the theoretical concepts and the empirical data related to a particular experimental situation. The application of the computer technique, and the evaluation of its usefulness are to be guided by the experimenter, and the benefits obtained from the simulation model depend upon the manner of its application.

The simulation is not the sort of deterministic system into which the experimenter simply feeds all his data, with his responsibility for the outcome ceasing at this point, and then waits for the computer to provide all the answers. In the present system, the experimenter's responsibility is to apply conceptual input into the system, according to the particular theoretical analysis of the experimental situation. That is, to some extent, the experimenter can influence, or bias, various aspects of the program's performance. In doing so he must justify the basis upon which he chooses to set the program parameters, and he must also justify his interpretation of the results provided by the program.

For reasons which will be made clear during this chapter, the function of the simulation program is not to apply a standard form of arbitary mathematical analysis to a plot of the empirical data points (e.g. the method of least squares) to obtain a function which best fits the data. Several quite different sets of data may give rise to exactly the same best-fitting mathematical function (e.g. if the data sets differ in amount of variance). Clearly, such methods are most useful in indicating overall trends in data patterns, but they cannot be used in the present kind of simulation, which has a qualitatively different conceptual basis, and a completely different purpose.

The simulation uses the computer to perform a sequence of operations, which are considered to be analogous to those performed by real subjects, in accordance with fundamental theoretical concepts incorporated in the computer program. The theory proposes an analytical description of what may be happening at the performance of each event in a given real task situation, and these concepts form the basis on which the program is written. Unlike the process of finding a function to fit the data, the simulation uses a quantifiable parameter to determine whether the program will perform in such a way as to produce results, over a given series of trials, which closely approximate real human performance in similar situations in as many aspects as possible.

Human cognitive processing performance is characterised by considerable variance both within and between subjects, and any useful simulation model must simulate such individual differences. A model which simply simulates trends in a set of empirical data is inadequate; it must provide results which closely match, in all important respects, a set of real results obtained from samples of different subjects. The program to be described does not simply obtain, or derive, a static mathematical function, rather it is a dynamic system which carries out a particular task.

7.4 The discussion which follows is in terms of the various theoretical concepts developed and explained in detail in earlier chapters.

The present simulation program incorporates several fundamental notions of the theory. Firstly the concept of a pattern as a quantity of information is used (p. 43). Because the computer employed was a digital computer, the concept of an effectively continuous quantity of information was achieved by considering a pattern as a single row array divided into 100 small segments. By separately labelling each of these 100 elements, different patterns were defined. Patterns sharing similar characteristics could be defined by incorporating these similar characteristics in two or more patterns in terms of the identical labelling of the appropriate segments in each pattern. The proportion of shared pattern characteristics (i.e. the degree of similarity between patterns) could be simply increased or decreased by varying the number of identically labelled segments common to the separate patterns.

Although the proportion of this pattern information processed by two subjects may be similar, individual differences in the selection of 'significant' pattern information are accounted for by allowing for considerable variance with respect to which particular segments in the array are processed. Also, the same subject may constantly process approximately the same proportion of pattern information on repeated exposures of the same pattern, but this proportion may well be referent to different sets of pattern segments on each different presentation of the pattern. (see p.47)

The amount of attention, or processing capacity, dedicated to the recognition of a pattern <u>on any presentation</u> may be defined in terms of the proportion of the total number of pattern elements which is processed on that presentation. Thus, under conditions in which only partial attention is dedicated to the processing of a pattern, this proportion is correspondingly smaller. In terms of the present theory, the size of this proportion may be dependent upon the degree of overlearning and the subjective probability of occurrence of an expected pattern. Clearly, where sizeable proportions of the total information content of a pattern are involved, in most cases the sets of elements forming these proportions will overlap.

Using this definition of a pattern, or more precisely, of the information content of a pattern, it becomes possible to specify redundant, or low priority, information areas (p.187) as those areas comprised of segments of the array which are least likely to be processed.

7.5 The above quite general theoretical notions were incorporated into a computer program which was concerned with the simulation of subjects' performances in the vigilance experiment reported in chapter VI.

The computer used for the simulation was a Nova 1220 mini-computer system, with 16K memory, teletype, dual-cassettes and a high-speed paper-tape reader. Some detail limitations were imposed on the scope of the simulation program by the 16K memory capacity of the Nova system (e.g. the use of 100 element single-row arrays rather than 100 x 100 matrix arrays). However, any limitations of this nature did not qualitatively affect the theoretical concepts underlying the simulation. These concepts were not tailored to fit the computer system used.

Consider the control group task situation in the vigilance experiment. A single complex pattern was repeatedly presented to the subject throughout the experiment. The subject was required to identify this pattern at each presentation. That is, he had to process at least the minimum proportion of the available visual sensory information referent to this expected pattern that was subjectively considered necessary to confirm its presence. On any presentation it was possible for a randomly occurring, infrequent signal to be contained somewhere in the picture. The subject was required to detect as many of these signals as possible. At each presentation he had to respond 'yes' or 'no' to the presence of a signal, in addition to the concurrent task of correctly identifying the picture.

According to the theory, signals which occurred in the picture were likely to be missed when they were not contained in the particular proportion of sensory information which was being processed at that time. Conversely, if a signal was contained in this proportion of sensory information, it would be detected.

For the purposes of the simulation, a signal was associated with a single element in the 100 segment array. The signal could be 'positioned' at any chosen element, and this position could be varied between signal occurrences.

7.6 In accordance with the foregoing principles, what the simulation program did was to execute a prescribed number of presentations of the pattern, or 'trials'. The number of these trials was chosen 'a priori'. On some of these presentations a signal was contained within the array. The occurrence of the signals with respect to particular trials and positions within the array could be randomised automatically by the computer according to a prescribed total number of signals. Alternatively, the signals could be included on particular trials, and at specific positions within the array, which were selected beforehand by the experimenter.

The proportion of the pattern information which was processed on any individual trial was a criterion value, 'k'. (see p.48). 'k' consisted of a set of k elements of the 100 element array. It was not restricted to any particular area of the array. In this way, on successive trials, k could be the same, but the actual elements forming the numerically identical sets processed on each trial could be different, although where k was relatively large (> 50) they would always overlap to some extent. In the simulation, for each trial the actual set of 'k' adjacent elements was always chosen at random from the array, so that its specific position could never be precisely predicted from trial to trial, even where k was the same.

At this point, the concept of 'k', and the way in which it is to be used in forthcoming discussion should be clarified. k has been defined as a set of elements of the 100 element array, the numerical value of k being the actual number of elements forming k. k is considered as the proportion of the pattern information processed on any given trial. Clearly, then, because the actual numerical value of k may vary from trial to trial, when using the term 'k' as a quantifiable parameter of attention in a general sense, for example, in relation to overall attention during a particular experiment, 'k' refers to the total range of values within which k may vary randomly. Because of the variance of attention across time, no meaningful single value of k may be taken as representative of 'k' for the whole experiment, unless, of course, k constantly varies within the same narrow range on every trial, in which case, an overall mean k value, together with the statement that attention did not lapse, could be used. Thus, to summarise this point, a single value of k is meaningful for a particular trial, but over a series of trials, k must be regarded as typifying a particular range of numerical values within which the actual value of k varies randomly. (A general expression showing how k is determined by the computer on each trial is given later in the chapter).

In the program k could be selected as a fixed constant, or it could be allowed to vary randomly from trial to trial within a prescribed range of maximum and minimum values, k max and k min. Also, the value of k could be varied randomly in such a way that the average value of k gradually decreased over a large number of trials to simulate a lapse of attention over a given time period. Similarly, the average value of k could be made to increase to simulate an increase in attention. The range within which k was allowed to vary could be altered across trials (i.e. in order to simulate the situation where attention is generally less, but is more variable from trial to trial). Alternatively, attention could be allowed to lapse with a constant range of k across trials.

Clearly, then, if k is small, the probability of detecting a signal is less than when it is large. The diagram shown in Fig. 14 illustrates this point in the case of the present program. The argument here is conceptually identical to that illustrated earlier using Venn diagrams.

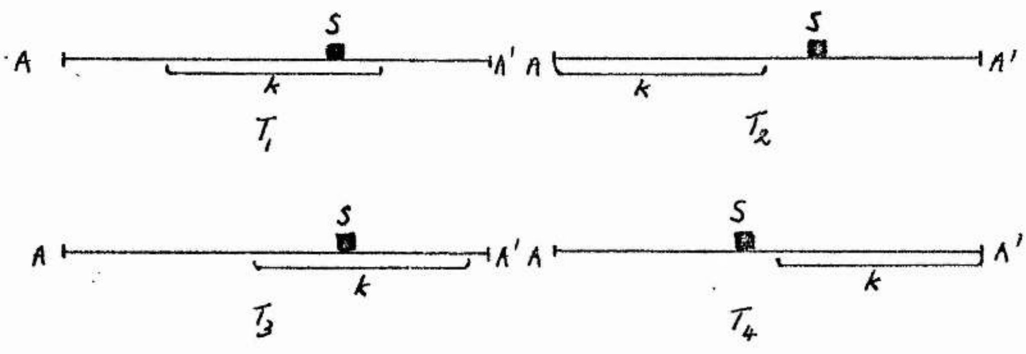


Fig. 14

In this figure AA^1 is the 100 element single-row array representing the total information content of a pattern, and k is the criterion of attention described above. T_1, T_2, T_3, T_4 represent four consecutive presentations of the same pattern, AA^1. In each case, the numerical value of k is the same. However, the figure illustrates the way in which the actual set of k elements processed may vary from presentation to presentation.

S represents a signal positioned at one element in the pattern AA^1. The diagram shows how S will be detected on trials T_1 and T_3, but not on trials T_2 and T_4. Because the position of k is randomly chosen, it cannot be predicted with any certainty on which specific trials the signal will be detected. Similarly if the numerical value of k is allowed to vary randomly within a wide range, it cannot be predicted on which trials a signal will be detected. It should be noted at this point that, for the purposes of the program k consists of a set of adjacent elements. There is no theoretical reason why k, which is conceptualised purely as a proportion of information, could not be composed of a given number of non-adjacent elements of the array.

In accordance with the concepts of the present theory, the greater the proportion of total processing capacity dedicated to the processing of real visual sensory information relevant to a particular pattern, the greater is the proportion of the total possible information content of the pattern that is processed - i.e. the greater will be the value of k. Thus, the value of k at any instant refers to the percentage of the total information from a given pattern which is being processed - i.e. the amount of total processing capacity (or amount of attention) which is dedicated to the processing of visual information from that pattern. (see also p.227).

In the present program no position of k could be selected such that it would fall outside either end of the array. Consequently, because of the nature of the randomising process, signals close to either end of the 100 element array were somewhat less likely to be detected. Thus, these end areas of the array could be usefully conceptualised as low-priority information areas (p.187) within the array. Detection of signals associated with elements in these areas was especially unlikely when 'k' was small - i.e. when attention had substantially lapsed. Note that these signals were no less 'discriminable' than identical signals associated with other parts of the array, but because of their location within these low priority information areas, they were likely to be detected less often.

A complete copy of the simulation program written in Extended BASIC is included in Appendix V. Using this program, any number of simulated experiments could be run, and the effects of altering the attention parameter k and the positions of signals could be investigated. By this means, the quantitative values and ranges of these parameters which most closely approximated the performance of the real subjects in the vigilance experiment could be obtained.

Thus, the range of k values which most closely simulated the empirical performance data obtained with real subjects could be determined by a method of successive approximations. On this point, it is important to emphasise that the performance data produced by the computer program had to simulate subjects' performances in relation to:- 1) the mean number of signal detection failures for the group; 2) the individual differences in signal detection performance between subjects in the group; and, 3) the overall pattern of detection failures across trials. To simulate correctly only one of these factors (e.g. mean signal detection performance), is inadequate.

The initial starting values of the ranges of k which were used in the method of successive approximations were chosen on the basis of a consideration of the theoretical conceptualisation of the global experimental task situation, together with the empirical results actually obtained in the real vigilance experiment. Initial choice of the k values was not arbitrary. If the theoretical basis and evaluation of the empirical data were soundly based, then, provided the qualitative concepts of the simulation program were also sound, the number of successive approximations necessary to produce results closely similar to the real ones obtained should be minimised. If, in fact, this number were excessive, it would indicate fundamental problems in either the computer program or the theoretical analysis. (In the present case this actually happened during development of the program, when repeated running of the simulation at unexpectedly low ranges of k produced the correct overall mean numbers of signal detection failures, and the correct variance, but not the correct distribution of misses if attention were lapsing. Further, the program was failing to detect signals in the low priority area at one end of the array, and detecting all signals in the corresponding area at the other end of the array. This finding led to the discovery by the programmer of several undetected errors in the program.)

The basis upon which the initial ranges of k were chosen will be outlined in the description of the simulation.

7.7 Computer simulation of the vigilance experiment.

(i) Apparatus.

The apparatus used in the simulation experiments was the Nova computer system, in conjunction with the simulation program described earlier.

(ii) Subjects

For each experiment, the program parameters of the simulation were re-cycled 10 times to simulate 10 different subjects. Because of the degree of randomness written into the program, the chances of two subject performances being identical in all respects were low. This facility provided for individual differences between subjects with respect to processing strategies and selection of 'significant' pattern information, while simulating overall performances of the sample according to the same fundamental set of general theoretical concepts.

(iii) Procedure

For all the simulated experiments, signals were programmed to occur at selected positions within the array on 43 particular trials. The figure of 43 was chosen to match the number of signals used in the real vigilance experiment. There were 309 trials, or pattern presentations, in each run.

TABLE XX

Trial numbers and signal positions

Signal No.	Trial No.	Position No.
1	4	56
2	12	65
3	28	47
4	30	38
5	44	43
6	52	61
7	62	54
8	65	46
9	70	54
10	73	47
11	79	81
12	89	44
13	95	42
14	106	57
15	112	49
16	117	53
17	118	46
18	134	84
19	138	19
20	144	43
21	152	61
22	156	39
23	164	29
24	169	41
25	187	60
26	195	18
27	207	32
28	219	38
29	224	50
30	230	57
31	236	42
32	253	21
33	257	46
34	267	40
35	270	68
36	274	49
37	276	51
38	278	80
39	284	26
40	291	28
41	295	90
42	299	47
43	309	53

Table XX shows the trial numbers on which signals occurred, together with the actual positions of the signals within these arrays, the elements of the array being numbered 1 to 100. A number of the signal positions were selected so as to be considerably distant from the mid point of the array to simulate the occurrence of signals in low priority information areas. The relative distribution of the 43 trials on which signals occurred across the 309 trials was the same as for the 43 trials containing signals in the control group of the real experiment. The actual number of 618 trials used in the real experiment could not be used in the simulation as this exceeded the 16K memory capacity of the Nova system.

An important factor involved in the formulation of the present concept of a 'pattern' was that of individual differences in relation to what aspects, or features, of a pattern were subjectively considered 'significant'. If every subject processed <u>all</u> the information in the patterns, defined in the program as 100 element arrays, then, clearly, there would be no provision for individual differences under conditions of maximum attention. Further, if we assume that a subject is processing <u>all</u> the information in the pattern, then, by definition, he will <u>always</u> detect a signal, no matter where it is situated in the pattern. Consequently, to determine the degree of flexibility in terms of individual differences to be allowed for in the simulation using the signals in table XX, the program was first set to run, with the range of k being kept <u>constant</u> across the experiment (i.e. no attention lapse), k was set at a maximum of 100 (i.e. in which case <u>all</u> the pattern information would be processed), and allowed to vary randomly through a 10 element range, i.e. so that the minimum k value was 90. This range was to provide for some variance in attention from trial to trial. By repeatedly running the program, the maximum value of k was lowered by 5 segments at a time, keeping the range of random variance of k constant, until signals were just beginning to be missed. It was found that, when the range of k was 100 - 90, no signals were missed. When the range was 95 - 85, no signals were missed, but when the range was 85 - 75, single signals were occasionally missed by several of the 10 subjects over two 'runs' at this k range. A mean of 4 signals per run were missed over the two runs, no single subject missing more than one signal. When k was lowered to the range 80 - 70, a mean of 12 signals were missed over two executions of the program.

On this basis, to enable the simulation to have some flexibility with regard to the selection of the position of k within the array, and thus simulate individual differences at maximum attention, and to include some redundancy in the perception of the pattern array, an upper limit of 85 was allocated to k for both experimental and control groups. In general terms, this meant that 85% of the total information content of the pattern needed to be processed for consistently accurate pattern recognition performance.

Also incorporated in the simulations for both experimental and control groups, was a general attention lapse towards the middle of the experiment, with an increase back to maximum attention towards the end of the experiment. This was done because results of the real experiment indicated a similar general lapse of attention over all subjects during the hour-long experiment, for <u>both</u> experimental and control groups. Reference to Fig. 13 shows that although the amount of lapse was less for the experimental group, its pattern was the same as for the controls.

For the simulated subjects, attention was made to lapse across trials in a non-linear manner, according to a square law.

Attention was made to lapse in a non-linear manner, because existing evidence regarding the effects on attention, or capacity, of monotonous or boring tasks suggests that such effects are not linear with time, performance often tending to 'fall off' exponentially (Welford, 1968). If such an assumption were unfounded, this should become apparent from an analysis of the distribution of signal detection results of the simulation compared to the real experiment.

Prior to any simulation run in which attention lapsed, the minimum value of the upper limit of k was selected (k max (min)), together with the maximum value of the lower limit of k (k min (max)). During the simulation, at each pattern presentation, the program first calculated the numerical value of the lapsed upper and lower limits of k according to the square law, and then randomly selected a value of k within these limits. This value of k was used for that trial. In this way, if the range of values through which k was allowed to vary was large, the random selection of the k value at each trial meant that there was not necessarily a constant sequential decrement, or increment, in the k value from trial to trial, but that the general trend of k was determined by whether attention was lapsing or increasing.

The diagram shown in Fig. 15 illustrates this notion, and shows diagrammatically the parameters which determined the range and distribution of k.

To outline the process in detail, for each separate trial, the value of k was determined by the computer in the following way:-

Let I = the actual trial number (= from 1 to 309 in the present experiment)

N = the total number of trials (= 309 in the present experiment)

A constant V was chosen such that the values of V range from $1 \rightarrow 0 \rightarrow 1$ as I ranges from $0 \rightarrow \frac{N}{2} \rightarrow N$. That is, at the mid point of the experiment, trial no. $\frac{N}{2}$, V has the value 0.

Now, $V = \left(\frac{2I - N}{N}\right)^2$, so that when:- $I = 0,\ V = 1$

$$I = \frac{N}{2},\ V = 0$$

$$I = N,\ V = 1$$

V is used to determine the overall non-linear variation of k across the experiment.

Referring to Fig. 15, a value, K8, is calculated such that

K8 = K max (min) + V (K max - K max (min))

This gives the maximum value of k for trial I, being based on the maximum values of k selected. A value, K2, is calculated such that

K2 = K min + V (K min (max) - K min)

This gives the minimum value of k for trial I, being based on the minimum values of k selected.

Finally, a value of k to be used for trial I is selected randomly from within the range of maximum and minimum values of k determined for that trial, so that the computer equation, written in BASIC is

K = Int (0.25 + K2 + RND * (K8 - K2)).

The above is the procedure by means of which the value of k is determined anew on every trial. The derivation of k is independent for each trial, and is not contingent upon the specific value of k in previous trials. The general trend of attention lapse, within the overall ranges chosen at the beginning of the run is determined by V, which is a function of the actual trial number.

For each trial, once the value of k has been calculated, it is then randomly allocated to a position in the 100-element array. If a signal is contained in that portion, it will be detected. Note that, even when k is relatively small, because of the random allocation of the position of k, it cannot be precisely predicted whether or not a signal will be detected on the trial if it is contained in the array. This means that, as in the real experiment, some signals can be detected even when attention has lapsed to its minimum.

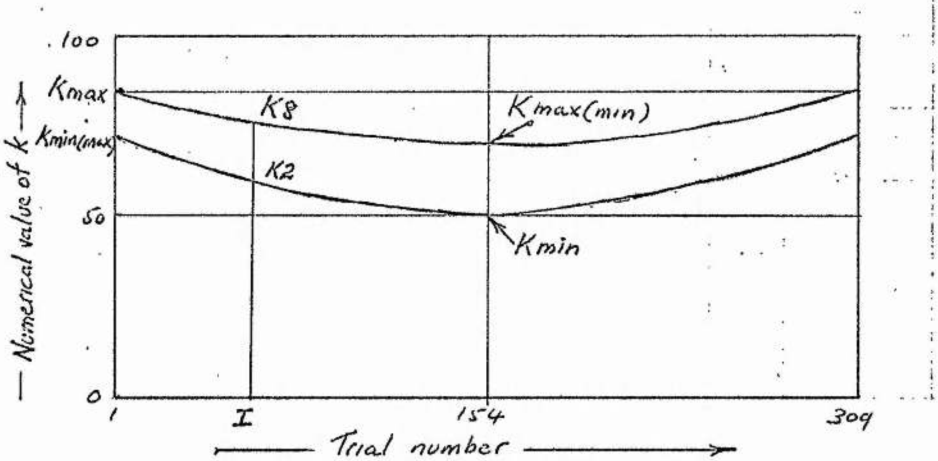


Fig. 15

To summarise, referring to Fig. 15, at trial I, the program first calculates K_8 and K_2, and then randomly selects a value of k within this range. This k value is then used for trial I. The numerical values of k always fall within the shaded area on the diagram. For the simulation represented by

Fig. 15, attention lapses (i.e. tends to become less) during the middle period of the simulated experiment.

For each 'subject', the program printed out the following information:-

1) Number of signals presented;
2) Number of signals detected;
3) Number of trials;
4) Number of correct trials;
5) The numbers of the incorrect trials.

5) showed the actual trials on which signals were not detected. The program always recognised the overlearned patterns correctly (as did the real subjects), and therefore the trials which were 'wrong' represented only signal detection failures, and not recognition errors. Fig. 16 is an example of an actual print-out for one simulated subject.

```
NO. OF SIGNALS PRESENTED=  43
NO. OF SIGNALS DETECTED  37
NO. OF TRIALS =        399
NO. OF CORRECT TRIALS=  393
TRIAL NO'S WRONG ARE :-
 133 , 152 , 164 , 195 , 253 , 257 ,
```

Fig. 16

A) Control group.

By the method of successive approximation outlined earlier, using the upper limit of k as 85, for the reasons explained, performance of the control group was simulated. Because the real control group situation involved only a single pattern, compared to the large number of patterns of the experimental group, the allowed variance of k at conditions of maximum attention was 7 elements (slightly less than the 10 used in the determination of the overall k max of 85 for both groups).

Because all the control subjects always responded correctly at <u>every</u> presentation of the single picture during the experiment, attention to the task obviously never lapsed completely. Subjects were processing at least a sufficient proportion of the pattern information to carry out this task. However, the results showed that the extent of the attention lapse was clearly quite considerable, and all control subjects stated that during the experiment they had started to think about other things. On consideration of these factors it was decided to simulate an allowed lapse to a range of $\frac{1}{3}$ to $\frac{1}{2}$ total attention in the middle of the experiment.

The range of attention variance was chosen to become greater towards the middle of the experiment, because analysis of the real empirical results had shown that although a greater number of misses were associated with this period, many signals were still detected during this period, thus indicating greater variance of attention.

These initial assumptions appeared to be well founded, and the control group subjects' performances were accurately simulated in all respects after only 6 runs, which included checks of k ranges slightly above and below those finally achieved. The following illustrates the optimal ranges of k determined:-

Using the trial numbers and signal positions shown in Table XX, the ranges of k were set as follows (see Fig. 15):-

k max = 85
k min = 36
k max (min) = 50
k min (max) = 78

* note: examples of results using different k ranges are given later.

That is, over the 309 trials the attention parameter was maximised at 85 at the start and finish of the experiment, with the minimum value of k at these points being 78 (a range of 7 elements). At the mid-point of the experiment, the maximum value of the attention parameter k was 50, and the minimum 36, (a range of 14 elements). This meant that when attention had lapsed to its greatest extent, its variance was somewhat greater than when full attention was being dedicated to the processing of the pattern information. The experiment was run twice to simulate results for two 10 subject control groups using these parameters.

B) <u>Experimental group.</u>

In the case of the experimental group, the results showed clearly that attention had lapsed to a lesser extent than the control group. As noted earlier, the maximum k for both groups can be regarded as the same, as when subjects are 'fresh' the maximum amount of attention dedicated to the task should be the same for both groups. However, because of the very large number of pictures, with their associated varying degrees of subjective interest, and resultant individual differences in information processing strategies, the range of k for the beginning and end of the experimental group was made greater than the controls (20 vs 7).

The simulated results for the control group provided a range of k which produced a sample performance closely similar to the real controls, and on this basis, the lapsed values k for the experimental group were chosen to be greater than for the controls. It was considered that the large number of pictures were unlikely to be accurately discriminated, as they consistently were by all subjects, if less than half processing capacity were devoted to the task. Similarly, because of the constantly high amount of attention required to perform the picture identification task accurately, the allowable range of k was kept the same throughout the experiment. (= 20).

Once again, a small number of successive approximations (= 3) resulted in accurate simulation of the real experimental group results, indicating that the assumptions described above were sound.

The following shows the optimal ranges of k determined for the experimental group.

Using the same trial numbers and signal positions as for the control group (see Table XX), the values of k for the experimental group were set as follows (see Fig. 15):-

k max = 85	note: examples of results
k min = 55	using different k ranges
k max (min) = 75	are given later.
k min (max) = 65	

Thus, for the experimental group, the maximum amount of information being processed from the pattern at each presentation towards the start and finish of the experiment was of the same order as for the simulated control group. Also, attention lapsed in the same qualitative manner as for the control group. However, the <u>extent</u> of this attention lapse was less for the experimental group subjects than for the control group subjects. By definition, according to the concepts of the present theory, in order to consistently achieve correct performance on the multi-pattern identification task, subjects must process a greater amount of real sensory information from the pattern at each presentation. (i.e. k had to be greater). The results of the real experiment showed that all subjects did this accurately. Consequently, the amount by which k was allowed to lapse in the simulation of the experimental group was selected to be less than that for the control group. However, the range of k was kept slightly greater in the experimental group to simulate variance caused by the large number of patterns employed for that group. The simulated experiment was run twice to obtain results for two separate 10-subject experimental groups.

7.8 Results and discussion.

(i) Signal detection performance

The computer took approximately 20 minutes of real time for each 10-subject simulation.

A) Control group

The optimised signal detection performance results obtained for two simulated control groups, together with the equivalent results for the real subjects are shown in Table XXI.

The optimised simulation results for both control groups (I and II) were extremely similar to the results obtained by the real subjects. Note that the randomness allowed for in the simulation program successfully provided for considerable individual differences between the performances of the simulated subjects.

The mean results for both control groups were not significantly different ($t = 1.58$; 18 d.f), and, most importantly, the results of neither control group were significantly different from those of the real control subjects. (I: $t = 0.74$; 18 d.f; II: $t = 0.56$; 18 d.f). The results of further repeated simulations using the same parameters do not deviate significantly from the examples shown.

TABLE XXI

Simulated signal detection performance - control group

I		II		Real Experiment	
Subject No.	Total no. of signals missed.	Subject No.	Total no. of signals missed.	Subject No.	Total no. of signals missed.
1	7	1	6	1	11
2	6	2	5	2	7
3	7	3	7	3	10
4	8	4	7	4	7
5	10	5	8	5	5
6	7	6	3	6	7
7	8	7	8	7	9
8	9	8	9	8	4
9	8	9	7	9	6
10	11	10	9	10	10
Mean/SD	8.1/1.44	Mean/SD	6.9/1.75	Mean/SD	7.6/2.2

B) Experimental group

The optimised signal detection performance obtained for two simulated experimental groups, together with the equivalent results of the real experimental subjects are shown in Table XXII.

For this group also, the optimised simulation results were extremely similar to the results obtained by the real subjects. The mean results of the two experimental groups were not significantly different from each other, and neither were significantly different from the results of the real subjects. (I: $t = 0.68$, 18 d.f; II: $t = 0.11$, 18 d.f.)

As in the case of the control group, the pattern of results of the simulated subjects was virtually identical to that of the real subjects. Repeated simulations using the same

TABLE XXII

Simulated signal detection performance -

experimental group

I		II		Real subjects	
Subject No.	Total no. of signals missed.	Subject No.	Total no. of signals missed.	Subject No.	Total no. of signals missed.
1	3	1	2	1	2
2	3	2	2	2	1
3	5	3	4	3	2
4	3	4	5	4	3
5	4	5	3	5	5
6	1	6	2	6	7
7	2	7	1	7	3
8	6	8	2	8	2
9	4	9	5	9	0
10	6	10	6	10	6
Mean/SD	3.7/1.55	Mean/SD	3.2/1.6	Mean/SD	3.1/2.11

k parameters do not yield results significantly different from the two examples shown.

The difference between the mean signal detection performances of the optimised simulated experimental and control groups was significant at the 0.002 level, just as in the case of the real experiment. (I: $t = 6.22$; 18 d.f; II: $t = 4.66$; 18 d.f).

Note that the only difference between the simulations for the experimental and control groups was the degree to which attention lapsed during the experiment; it started and finished at the same maximum level for subjects in both groups. Note that the manner in which the upper value of k was determined for both groups shows that when there is no attention lapse with this maximum k, very few signals are missed. The important point here is that no signals are missed in either the real or the simulated experiments because of any problem of task difficulty. Detection of all signals is well within the capabilities of all subjects. Signal detection failures are entirely a function of attention lapse, i.e. a reduction in the amount of processing capacity dedicated to the analysis of real sensory information.

(ii) Analysis of patterns of detection failures for optimised simulation.

Each signal and the total number of misses made on that signal by all the simulated subjects in control group I is shown in Fig. 17. Note that, in a manner similar to the real experiment, 19 signals of the 43 presented accounted for all the misses in the control group (vs 17 in the real experiment). Equivalent results for the simulated experimental group I are graphed in Fig. 18. In the case of the simulated experimental group, 12 signals accounted for all the detection failures made by the group. (vs 19 in the real experiment). Reference to table XX shows that the signals missed most tended to be positioned toward the low priority information areas in the array, i.e. nearer to either end of the 100 element array.

Thus, in all essential respects, the overall performance of subjects in the optimised simulated experiments was very closely similar to that of the real subjects. The only important difference between the simulated and real situations was that the computer program made no provision for the simulation of false alarms. The reason for this omission was the limitation of the memory capacity of the Nova computer.

Fig. 17.

Results: Simulated vigilance experiment
Control group I

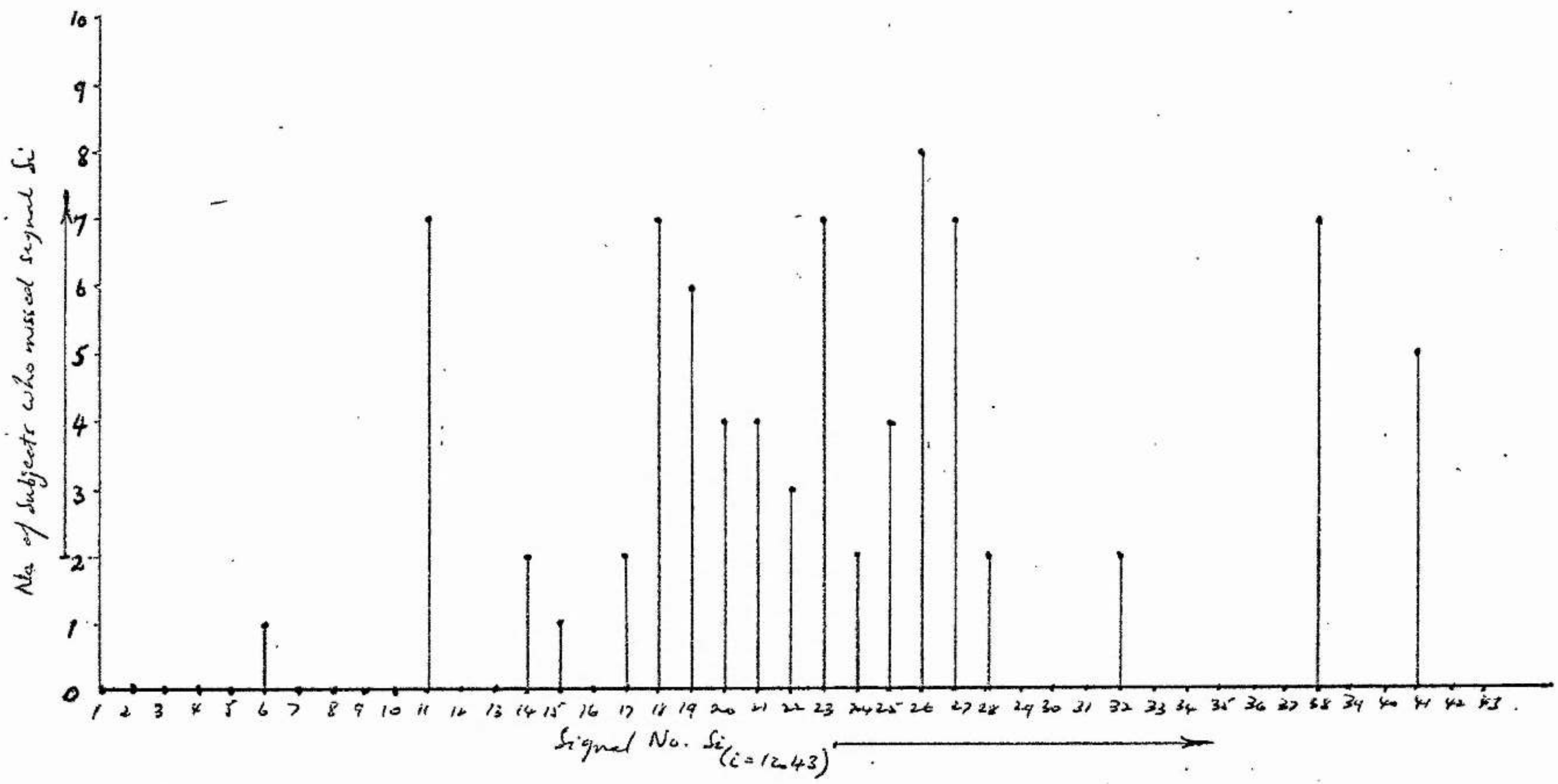
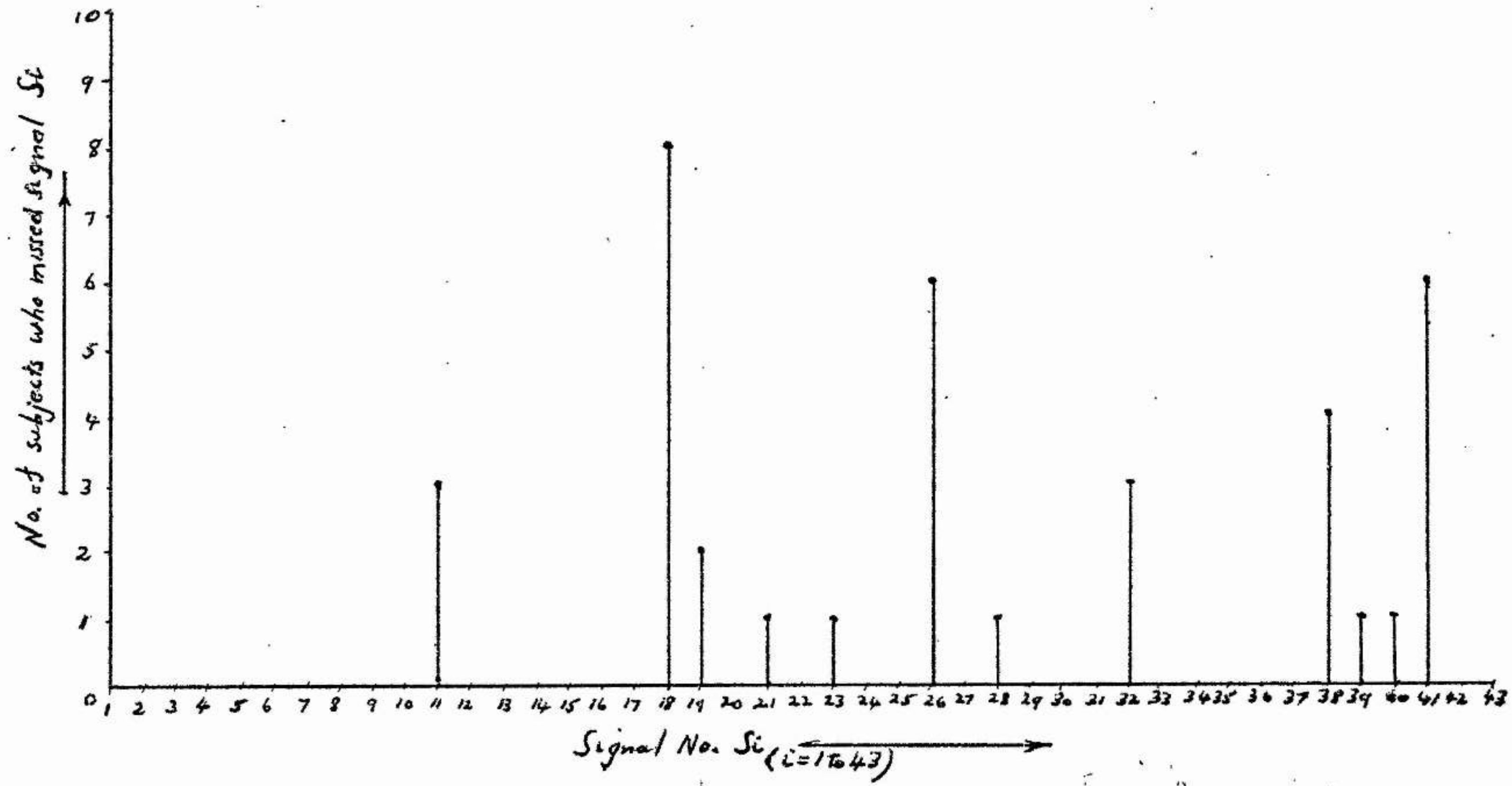


Fig. 18.

Results: Simulated vigilance experiment
Experimental group I.



However, the future provision of false alarms into an extended simulation program does not present special problems of programming.

The nature of the real false alarm data was discussed in Chapter VI (p.174). For the experimental group, the false alarm rate was very low, being only 1 in every 257 events. These false alarms were generally distributed randomly across the period of the experiment, or they occurred at the very beginning of the experiment, when the subject may not have been entirely certain of the nature of the signal. This result may be simulated by associating the very low probability of a false alarm with the trial number, and biasing it to be greater towards the beginning of the experiment, using a randomising process to insert false alarms on occasional trials throughout the remainder of the experiment. For the experimental group, analysis of the false alarm data showed that, in many instances, false alarms were associated with repeated presentations of the same pictures. This type of artifactual result can be simulated by having a generally high, but randomised, probability associated with a false alarm on the repeated presentations of the same pattern. Had 624 different pictures been able to be used in the real experiment, the artificially high false alarm rates achieved by the three particular subjects would have been eliminated. If such an experiment can be carried out, it will provide a more meaningful basis on which to simulate false alarms.

(iii) <u>Comparison tables showing examples of simulation results using 'k' values other than the optimal values.</u>

TABLE XXIII

A) Simulated control groups

	Range of k				Signal detection failures	
	K max	K min	K max(min)	K min(max)	Mean	S.D.
1	100	51	65	93	1.6	1.11
2	90	41	55	83	5.2	1.4
* 3	85	36	50	78	6.9	1.75
4	85	45	50	78	5.1	1.44
5	85	36	50	65	9.2	3.06
6	80	31	45	73	9.3	1.67

Key: 1 : Values of k uniformly increased by 15 above optimal.

2 : Values of k uniformly increased by 5 above optimal.

3 : * optimal values of k.

4 : Values of k allowing less attention lapse than optimal.

5 : Showing results for a control group with the same range of k variance at start and finish of experiment as for optimal experimental group.

6 : Values of k uniformly decreased by 5 below optimal.

These tables show that substantial differences in performance of the simulated subjects result from small variations in k (e.g. 5 elements). These results also indicate the soundness of the assumptions upon which the initial ranges of k were chosen. For example, the variance of k at the start and finish of the experiment was made smaller for the control group than for the experimental group, because of the use of only a single picture in the control group task, compared with 75 pictures for the experimental group. If, for a simulation run, the starting

TABLE XXIV

B) Simulated experimental groups

	Range of k				Signal detection failures	
	K max	K min	K max(min)	K min(max)	Mean	S.D.
1	100	70	90	80	1.0	0.89
2	90	60	80	70	1.5	0.92
* 3	85	55	75	65	3.2	1.6
4	85	55	75	78	2.1	1.04
5	80	50	70	60	3.9	0.9

Notes: 1 : Values of k uniformly increased by 15 above optimal.

2 : Values of k uniformly increased by 5 above optimal.

3 : Optimal values of k.

4 : Showing results for an experimental group with the same degree of k variance at start and finish of the experiment as for optimal control group.

5 : Values of k uniformly decreased by 5 below optimal.

and finishing range of variation of k for the optimal control group is made the same as for the optimal experimental group, with no other factors changed, then the resultant signal detection performance by the simulated group is too poor in comparison to the real control group subjects. Conversely, if the starting and finishing range of variation of k for the optimal experimental group is made the same as the optimal control group, with no other factors being changed, then the resultant signal detection performance by the simulated experimental group is too good in comparison to the real experimental group.

These simulation results appear to justify the assumptions upon which the range within which k was allowed to vary in relation to the same maximum value at the start and finish of the experiment was chosen to be different for the control and experimental groups. (p.212).

If it is accepted that the experiments described in this chapter demonstrate that a simulation program based directly on the present theoretical concepts is able to produce results which do not differ significantly in any way from those of real subjects, then what can be usefully said about the possible benefits of such a program? It has been shown that a system operating according to fundamental concepts of the present theory can be readily made to achieve performances statistically indistinguishable from those of a sample of real subjects. There is, therefore, some strong justification, in addition to that provided by the empirical data obtained using real subjects, for regarding the theory as useful in the understanding of human cognitive processing performance in these complex situations. Secondly, the values of the k parameters of attention used in the simulation may provide a useful guide to the estimation of this general parameter in human subjects. These values cannot be measured directly in the case of real subjects; however, the simulation program may enable them to be reliably inferred. That is, a meaningful quantitative index of the proportion of total cognitive capacity dedicated to the processing of sensory pattern information may be obtained by determining which values of k produce simulated performances similar to real performances in various situations. For example, if a separate second task of any kind were performed simultaneously with a vigilance task, the resultant increment or decrement in signal detection performance could be used in conjunction with the simulation program to ascertain the values of k appropriate to the single and dual-task situations. The difference between these values then provides an index of the proportion of processing capacity utilised in performance of the additional task.

In the case of the present experiment, a quantitative index is provided with respect to the degree to which attention lapses during the monotonous single pattern vigilance task performed by the control group, in comparison to the task performed by the experimental group.

Fig. 19 illustrates the ranges of the attention parameter k for both simulated experimental and control groups.

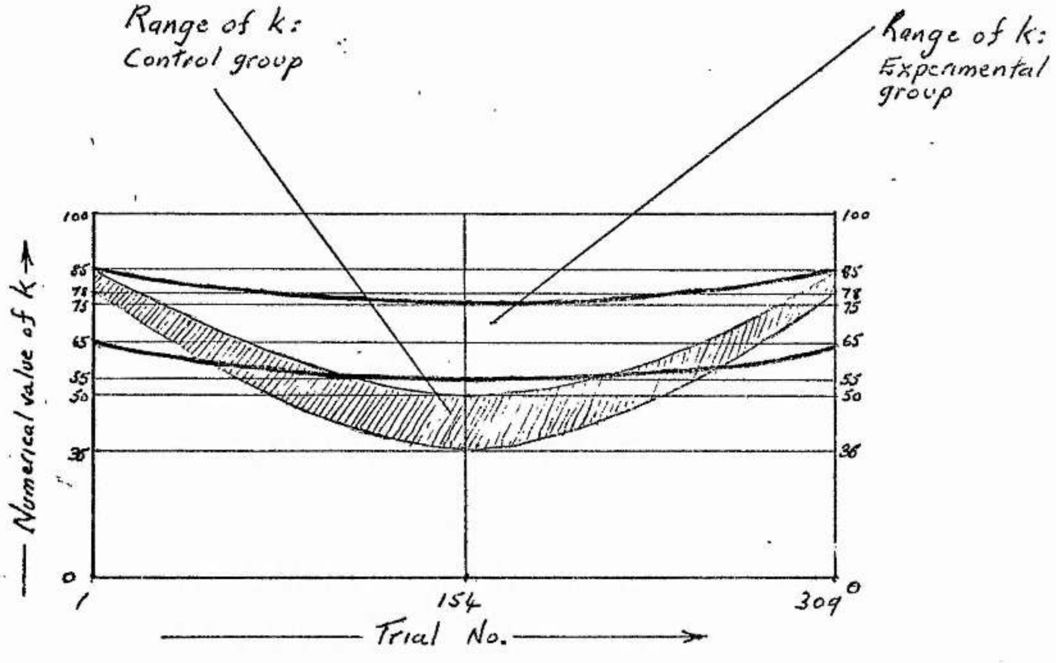


Fig. 19

By inference, it may be useful to assume that this is also the case for the real experimental and control subjects. An important advantage of this procedure is that the concepts are quite general and are not linked to any specific physical details of patterns. Nor are they linked to specific measures of the absolute information content of different patterns, as k is always a proportion of the total information content of a pattern. Similar k's for different subjects may well be referent to different physical aspects of the total pattern information content, but this does not affect the model, which is concerned only with proportions of total cognitive processing capacity. From these values of k determined by means of the simulation program, it becomes possible to make predictions with regard to the probability of a subject detecting alterations in overlearned visual patterns in situations where the proportion of real sensory pattern information being processed from the display is known. In other words, k may be useful in quantifying a human operator's reserve, or 'spare', processing capacity which he could employ to cope with increases in the cognitive load connected with the situation.

It is considered that the principles of the simulation procedures described in this chapter may well be extremely useful in the applied situations under consideration (p.7), and it is intended to further investigate this aspect in real complex man-machine environments.

Finally, it should be noted that because of the way in which 'k' is defined, and the way in which a 'pattern' is defined in the present simulation, the values of k referent to the proportion of the total information content of a pattern, and the proportion of total capacity dedicated to the processing of pattern information, are interchangeable. That is, if all capacity is dedicated to the processing of a given pattern, then all the subjectively relevant information from that pattern is being processed by the perceiver, i.e. $k = 100$. Similarly, if only half total capacity is dedicated to the processing of a pattern, then, by definition, in this case, $k = 50$.

7.9 Conclusions.

It is concluded that the simulation technique described in this chapter provides further empirical support for the theoretical approach of the thesis from another different standpoint. Further, the accuracy with which the patterns of real subject performances were simulated suggests that the simulation principles may facilitate the determination of a meaningful quantitative index of the proportion of cognitive processing capacity dedicated to a particular task. On this basis, reliable predictions may be made with regard to the limits of cognitive processing performance in that situation. In addition to providing support for the present theory, the simulation principles developed may be evolved into a useful tool for applied research.

Chapter VIII

8.1 This final chapter first sets out some general conclusions drawn on the basis of the research reported in the preceeding chapters, and then outlines the proposed future stages in the research program, which will be directly concerned with the application of the theoretical concepts and empirical results of the thesis to the investigation of human operator performance in real complex man-machine systems.

8.2 The most important conclusions relating to the outcomes of the particular individual experiments have been given in detail at the end of each relevant chapter. However, a number of broader concluding statements regarding the overall research program are put forward:-

It is concluded that the theoretical approach outlined and developed in Chapters I and II has been firmly supported by the empirical results of the experiments. A most important aspect of this support was that it came from a range of several independent and qualitatively different kinds of experiment, and from different types of analyses of the empirical data within each of these experiments. Thus, the empirical support for the central concepts of the theory is wide-based, and is not linked to a particular kind of experiment or method of data analysis. Given the intended scope of the theory, it is considered that such independent wide-based support is an essential adjunct to the validity of its fundamental ideas. The empirical evidence obtained in support of the theory indicates that its basic principles may be usefully applied with some degree of generality. Consideration of possible alternative theoretical explanations showed that the resultant predictions were in some respects contrary to the results observed.

A very important conclusion to be drawn from the thesis is that the new experimental paradigms and techniques which were developed as part of the research program are potentially useful in a number of existing areas of research, in addition to their primary purpose in relation to the investigation of the present theory. These methods were finally evolved only after extended periods of pilot experimentation with different apparatus configurations and stimulus materials. For example, as stated earlier, the solution of the various technical and methodological problems posed by the vigilance experiment were particularly difficult. However, these problems were finally effectively overcome to enable the setting up of the experiment as envisaged. In future experiments, it is planned to at least partially automate the time-consuming processes of recording the experimental videotapes and of the accurate analysis and cross-checking of individual subject records.

8.3 The fundamental concepts of internal-external inter-task interference has demonstrated the potential value of investigating the nature of human pattern-recognition using partial attention techniques in conjunction with overlearned patterns. If the low-priority, or redundant, information areas of overlearned patterns are those which tend not to be processed under conditions of partial attention, then these low priority areas may also represent the less subjectively 'significant' features of the array. During performance of divided-attention recognition tasks, probe signals or alterations embedded in these overlearned patterns should be less likely to be detected when they are located in redundant information areas of the pattern. By repeated testing using this procedure, it should be possible to map the 'insignificant' or low priority areas for a particular complex pattern. The remaining areas will consist of the subjectively 'significant' features of that pattern. Note that this procedure does not involve any arbitrarily chosen form of visual decay or fragmentation of the pattern. The definition of a pattern as a quantity of information, explained in detail on p. 43 , enabled problems of feature analysis and individual differences to be bypassed. However, in achieving this purpose, the work has provided potentially useful new techniques which may assist in resolving these complex problems.

8.4 The results of the work suggest that the possible role of imagery in all aspects of human perceptual performance is worthy of further consideration and investigation. The experiments reported in chapters IV and V, together with the results of Marks (1973), indicate that the VVIQ may be a most useful research tool for this purpose. It is suggested that in future experimental contexts where, in terms of the present theory, the imagery system might conceivably fulfil an important role in the conscious perceptual experience of the subject, the VVIQ could be administered beforehand and the resultant imagery ratings be analysed in relation to individual task performance for each subject.

8.5 Partial attention situations are common in the normal human environment. The research work of the thesis illustrates the importance of using such techniques in the laboratory. Empirical results which might be somewhat less artifactual, and thus more applicable to human performance in real situations, may be obtained in this manner. Welford stated in 1968 that the dual, or multiple task technique was "as yet still in its infancy" (p.134). It is hoped that the concepts of this thesis, and in particular the types of 'internalised' and 'externalised' task interference predicted and subsequently observed have added a new dimension to the potential benefits of this kind of research.

For example, the following speculative suggestion is proposed:- If it is the case that, under conditions of partial attention, only non-redundant visual sensory information referent to an overlearned pattern tends to be processed, then this selective factor indicates that, in certain situations, partial attention to a signal detection, or watchkeeping, task by a human operator may be of more benefit than full attention, provided that awareness of alterations to only the significant information areas of the display is all that is required of the operator. That is, it may well be that improved performance on particular types of task may result from only partial attention being dedicated to the performance of such tasks. The simultaneous performance of a secondary task may not be 'arousing' in the usual sense, but the increase in performance on the primary task could be due to the fact that, although less processing capacity is being dedicated to the primary task, it is more selective. Clearly, in such a situation, performance related to the detection of changes in the redundant areas of the visual display will be worsened by the concurrent performance of the secondary task.

These concepts provide an alternative to the arousal explanation of the results obtained by McGrath (1965), who observed an improvement in signal detection performance on an auditory vigilance task when it was paired with perception of interesting visual material irrelevant to the signal detection task. If the effect of the interesting visual material was to cause only partial attention to be dedicated to performance of the auditory vigilance task, provided that the subjects were aware in advance of the acoustic nature of the signal, then their attention to the auditory task could have been selective to only the non redundant areas of the sound spectrum, i.e. that of the sound of the signal. An obvious test of such an hypothesis would be to replicate McGrath's experiment using as signals a set of individually different sounds of the same intensity and duration as the expected auditory signals. The prediction from the preceeding analysis would be that sounds acoustically similar to those expected would be more likely to be detected than dissimilar auditory signals of the same intensity and duration.

8.6 A primary motivation of the research of the thesis was the investigation of the cognitive load problems associated with errors made by human operators in complex man-machine situations (p. 7) - in particular aircrew in advanced jet aircraft. Despite much research, from the state of the existing literature it was clear that there remains a critical lack of knowledge regarding the fundamental nature of human information processing in such situations. It was considered that in order to study meaningfully the relevant aspects of the applied situation, further pure research, both theoretical and experimental, had to be undertaken to clarify particular issues. Much of the applied research in this area has been restricted to a particular kind of psychological approach, the main concern of which has been the optimisation of the ergonomics of the pilot's work environment. With the primary applied psychological problems relating to aircrew performance now becoming increasingly associated with excessive cognitive, or mental, load, fundamental limitations of the 'traditional' approach are clearly apparent. (Chapanis, 1965; Gerbert, 1971; Falckenberg, 1974).

Burrows (1973) notes that "pilot error in the operation of equipment and controls of a type that did not exist 25 years ago is now becoming a critical element in accidents". Between 55% and 85% of aircraft accidents are now attributed to 'human error'. Haward (1974) points out that, in cases of serious accidents involving misreading of the altimeter, the previous preferred action was to investigate redesign of the altitude display information, even though thousands of pilots were using the instrument satisfactorily. Little attention was given to the study and analysis of possible cognitive psychological factors involved in the accident relating to why that particular pilot misperceived his instruments in the particular circumstances pertaining at the time of the accident. With the almost uniform achievement of high ergonomic standards in modern aircraft, the real and continuing problem of apparently unexplained instances of failure of human control performance in ergonomically satisfactory cockpits by well trained aircrews, is not yet understood. (Burrows, 1973).

The traditional approach has ignored many other important areas of psychological research, yet the work described in this thesis indicates that the cognisance of research information from a number of traditionally separate areas of information processing psychology (e.g. cognition, imagery, perception, memory) may well offer a fresh approach to applied problems, and perhaps offer some new solutions, or, at least, allow the asking of new questions.

8.7 The experiments reported in the thesis have demonstrated some particular effects of intertask interference. It has been shown that, while engaged in internalised thinking, a subject may simultaneously experience normal perception of an expected over-learned complex pattern presented to him. However, the real complex pattern actually displayed to the subject may differ considerably from the expected overlearned pattern without the subject apparently being consciously aware of either the existence or the nature of this difference. A number of eminent investigators (e.g. Bartlett, Bruner, Welford, Piaget, Neisser) have expounded the notion that much of what is experienced perceptually is actually inferred, i.e. that conscious perceptual experience is often a composite of real and memory-derived information. This thesis has provided theoretical reasons why this may be so, and has proposed and investigated a system by means of which this might occur.

To relate these concepts to the applied situation of flying, consider, for example, the case of a pilot who misreads his altimeter, a continuing cause of many serious accidents. This kind of failure on the part of the pilot to process correctly what the altimeter is showing is typically categorised as 'pilot error' in post-accident investigation reports. However, in terms of the present theory, this pilot may not, in fact, be making an 'error' of perception in the accepted sense of the word. If, according to the expected configuration of the aircraft, the pilot expects to see a particular altitude value indicated by his instrument, a value which, through extensive previous training and experience of that particular aircraft configuration, is highly over-learned, then he may consciously experience real perception of the altimeter reading which he is expecting. In this case, a critical part of the pilot's perception of his instrument is composed of over-learned information held in the pilot's memory.

This effect will be enhanced if the pilot is either not concentrating fully on the flying task (e.g. if he has become complacent as a result of many incident-free operations), or if he is engaged in a difficult cognitive decision-making task at the time (e.g. if he has become confused regarding his present position relative to his intended destination). Note that the error of 'misreading' the altimeter is not caused by any reduction in visual acuity concurrent with either the excessive cognitive loading, or insufficient attention being dedicated to the flying task. The pilot may consciously perceive the expected, but incorrect, reading on the altimeter with ample clarity, but the information component of this perceptual experience is derived from memory.

This analysis is not concerned with any ergonomic deficiencies of the altimeter display. Viewed in this way, the performance failure may not represent an 'error' on the part of the pilot, but rather a basic inability of the limited information processing capabilities of the human cognitive system to cope with the demands of the situation.

8.8 A new conceptual approach to vigilance-type situations was suggested by the theory developed in the thesis. Vigilance tasks are common to a wide range of tasks in civil and military flying. They normally involve sustained concentration over long periods of time, during which a faint and/or infrequent signal such as a 'blip' on a radar screen, may occur. The operator's task is to detect these signals. Such radar watchkeeping tasks are typically found in, for example, maritime reconnaissance flying, where an operator must watch a radar screen, with the aim of detecting a signal indicating the presence of an enemy submarine. It is considered that the cognitive approach to vigilance, and the new experimental techniques concurrently developed, which have been shown to improve signal detection performance, offer possible practical application to some real vigilance task situations.

Some previous vigilance experiments have investigated the effect on signal detection performance of a concurrently performed 'arousing' secondary task of some kind. However, the present approach is quite different in that the 'secondary' task and the primary signal detection task are directly and inseparably inter-related at a visual sensory level. Existing computer-generated display techniques may be utilised to explore the possibility of superimposing an artificial visual complex pattern identification task upon a real vigilance or radar watchkeeping task. Already such techniques have been used to present 'artificial' signals to operators.

8.9 Finally, the new simulation techniques developed in the thesis provide a means of quantification of a parameter of attention which is not directly observable during a real subject's task performance. This computer-derived parameter is useful in that it is of a quite general, and not task specific nature (unlike a transfer function). It is hoped to apply this technique, using a larger computer, to the applied situations under consideration. For example, the intention is to investigate, using a flight simulator, pilot performance in specific flight situations in which the requirement for making complex and difficult decisions is coincident with the requirement for accurate visual monitoring of the instrument and control displays. From the experimental evidence already accumulated, it is predicted that pilots who are confronted with the necessity to make a difficult decision, or set of decisions, about the state of the aircraft will be more likely to fail to detect deviations of instrument or control positions from the normal, expected, visual configuration. In more general terms, we expect to show that the pilot attempting to solve a difficult mental problem, i.e. to arrive at the correct decision regarding the most appropriate cockpit drill in a given situation, may simply fail to see, in a very real sense, unexpected deviations of his instruments or controls from the normal during this period. What the 'normal' instrument and control configuration is depends, of course, on the particular global configuration of the aircraft (e.g. take off, climb, descent, final approach etc). However, the pilot expects to see that particular visual pattern appropriate to the mode of the aircraft, and these patterns are, of course, over-learned, i.e. able to be completely specified from memory information acquired during extensive training.

The simulation techniques can be used to quantify the proportion of total capacity a pilot is dedicating to the processing of real visual sensory information from his instrument and control displays. The procedure may then also be used to simulate the effect of varying degrees of cognitive load on perception of these displays. Those information areas in which changes are least likely to be detected under the conditions of partial attention associated with high cognitive loading may be determined in this manner.

8.10 Joynson stated in 1971 that, with regard to perceptual studies as a whole: "the re-examination of concepts is currently more important than the continued accumulation of experimental findings of the traditional kind", and that "the divorce between theoretical intention and experimental practice might be described as <u>the</u> contemporary problem in perception". (1971, p.415). Such factors have been of prime importance to the motivation and nature of the research reported in this thesis, and it is hoped that the work has provided a useful contribution to the resolution of these problems.

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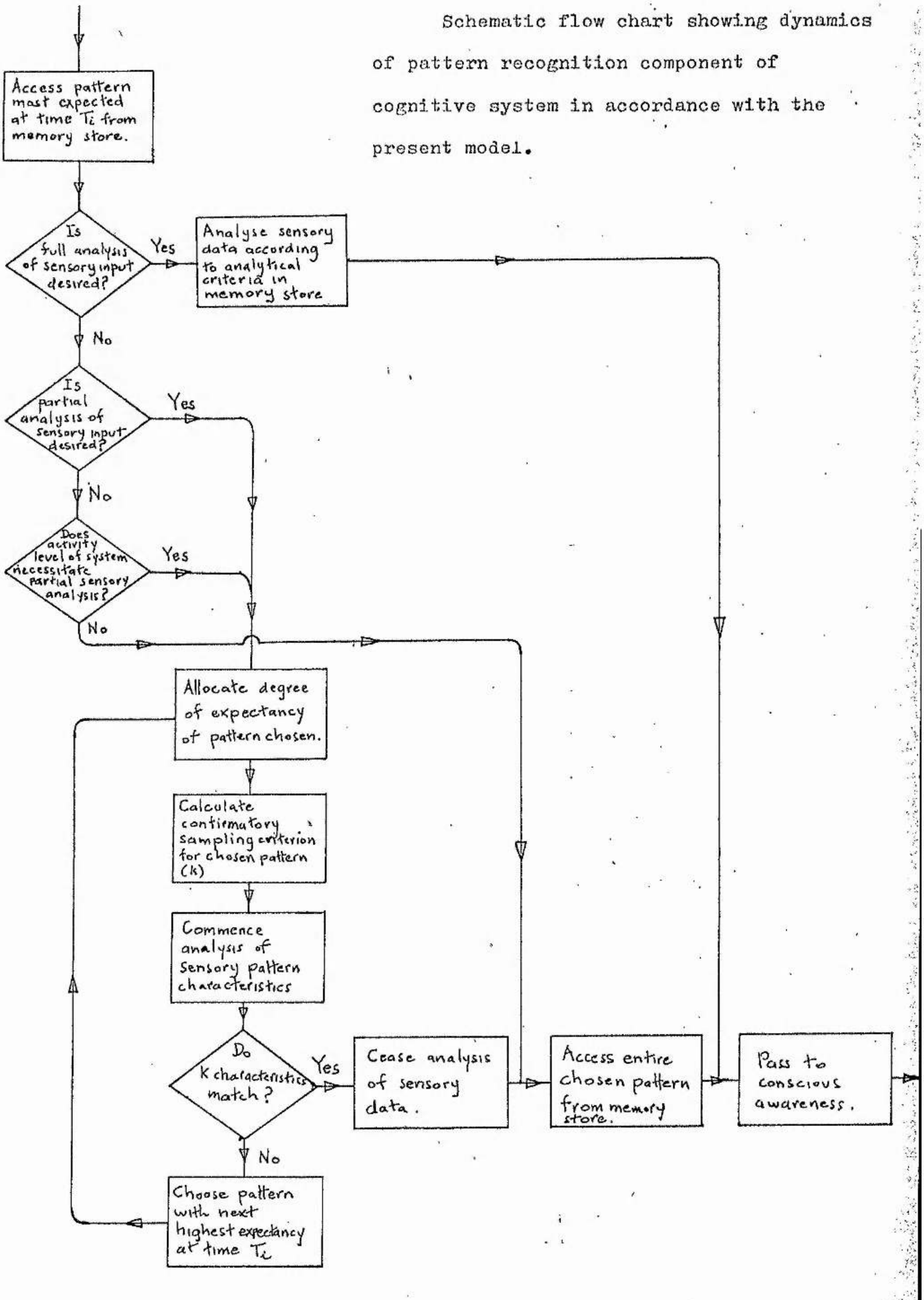
APPENDIX I

Schematic flow chart showing dynamics of pattern recognition component of cognitive system in accordance with the present model.



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APPENDIX II : THE V.V.I.Q.

Rating	Description
1	'Perfectly clear and as vivid as normal vision'
2	'Clear and reasonably vivid'
3	'Moderately clear and vivid'
4	'Vague and dim'
5	'No image at all, you only "know" that you are thinking of the object'

Questionnaire

*** For items 1-4, think of some relative or friend whom you frequently see, (but who is not with you at present), and consider carefully the picture that comes before your mind's eye.

Item

1. The exact contour of face, head, shoulders and body.
2. Characteristic poses of head, attitudes of body, etc.
3. The precise carriage, length of step, etc., in walking.
4. The different colours worn in some familiar clothes.

*** Visualise a rising sun. Consider carefully the picture that comes before your mind's eye.

Item

5. The sun is rising above the horizon into a hazy sky.
6. The sky clears and surrounds the sun with blueness.
7. Clouds. A storm blows up, with flashes of lightning.
8. A rainbow appears.

*** Think of a shop which you often go to. Consider the picture that comes before your mind's eye.

Item

9. The overall appearance of the shop from the opposite side of the road.

10. A window display including colours, shapes and details of individual items for sale.

11. You are near the entrance. The colour, shape and details of the door.

12. You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.

*** Finally, think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.

<u>Item</u>

13. The contours of the landscape.

14. The colour and shape of the trees.

15. The colour and shape of the lake.

16. A strong wind blows on the trees and on the lake causing waves.

APPENDIX III

Photographs used in the picture memory experiments reported in Chapters IV and V.

Note. The category numbers adjacent to each homogeneous set of photographs (S_1, S_2, S_3 etc..) correspond to those used in the tables and graphs in Chapters IV and V.

S_1

S_2

S_3

S_4

S_5

S_6

S_7

S_8

S_9

S_{10}

APPENDIX IV

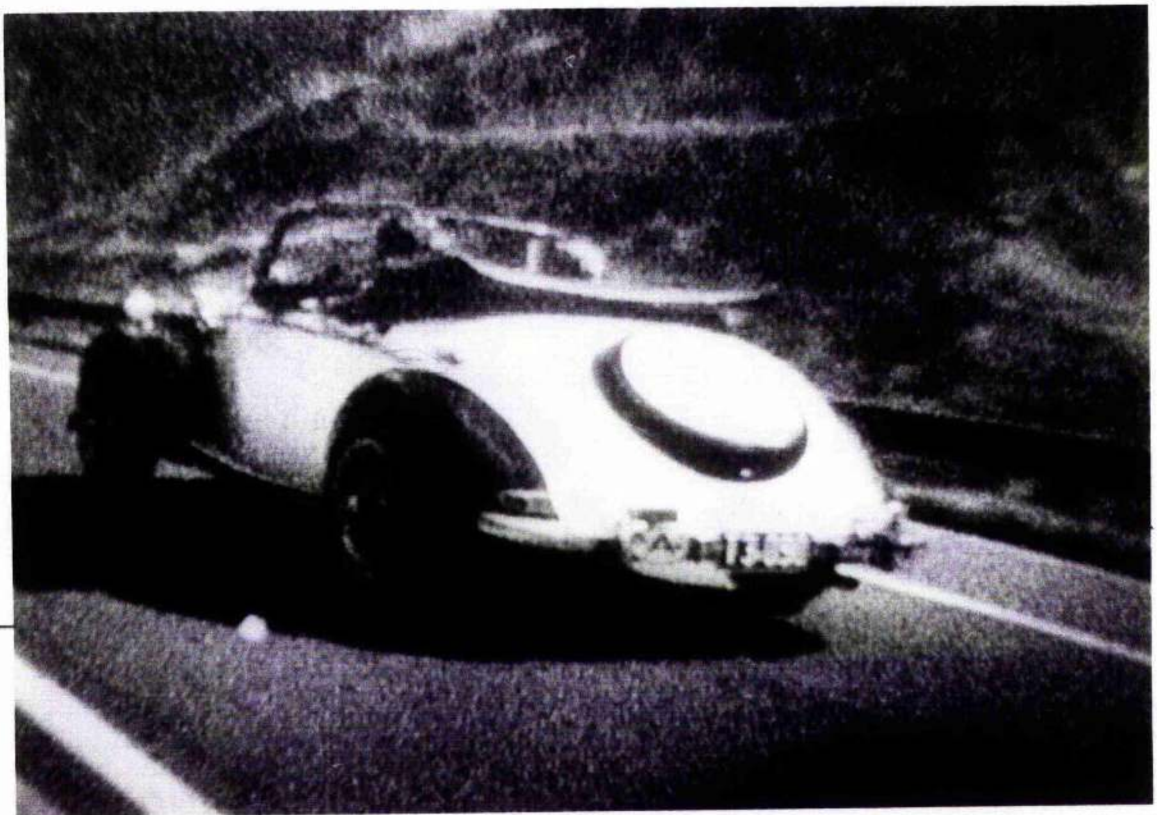
Examples of pictures and signals used in the vigilance experiment.

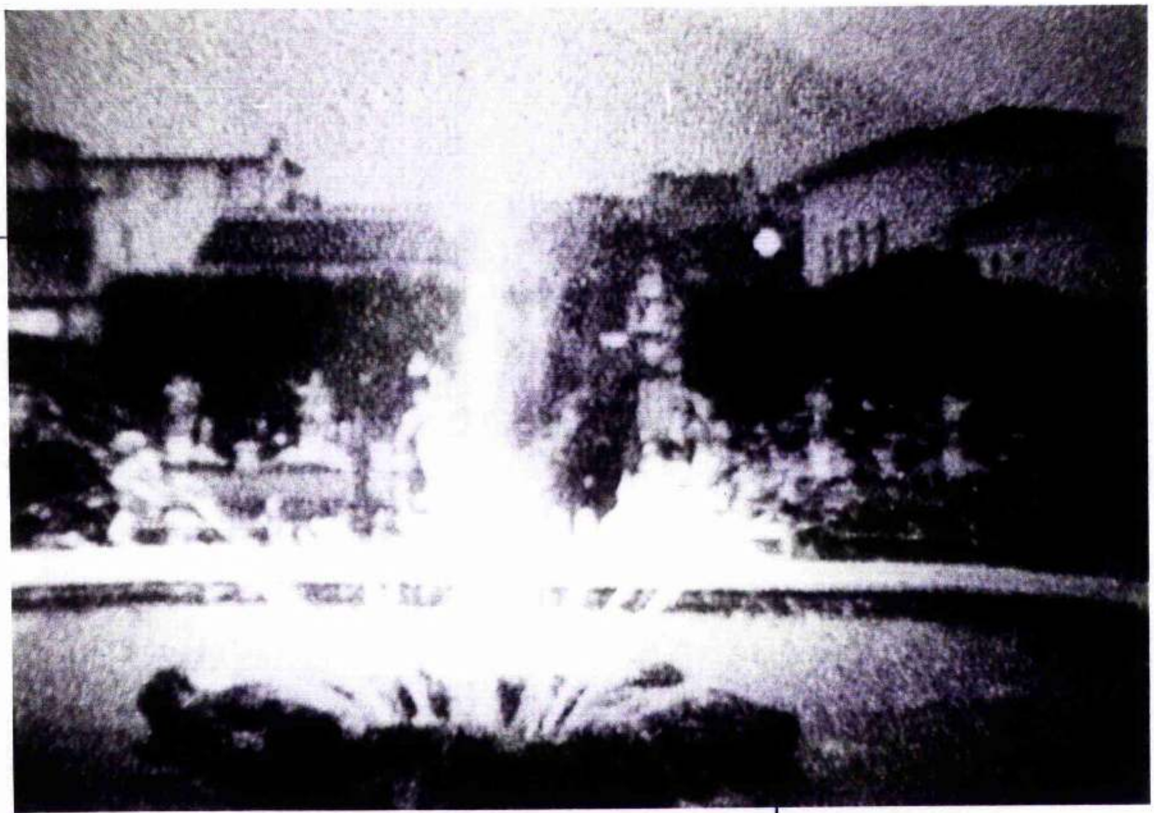
Notes

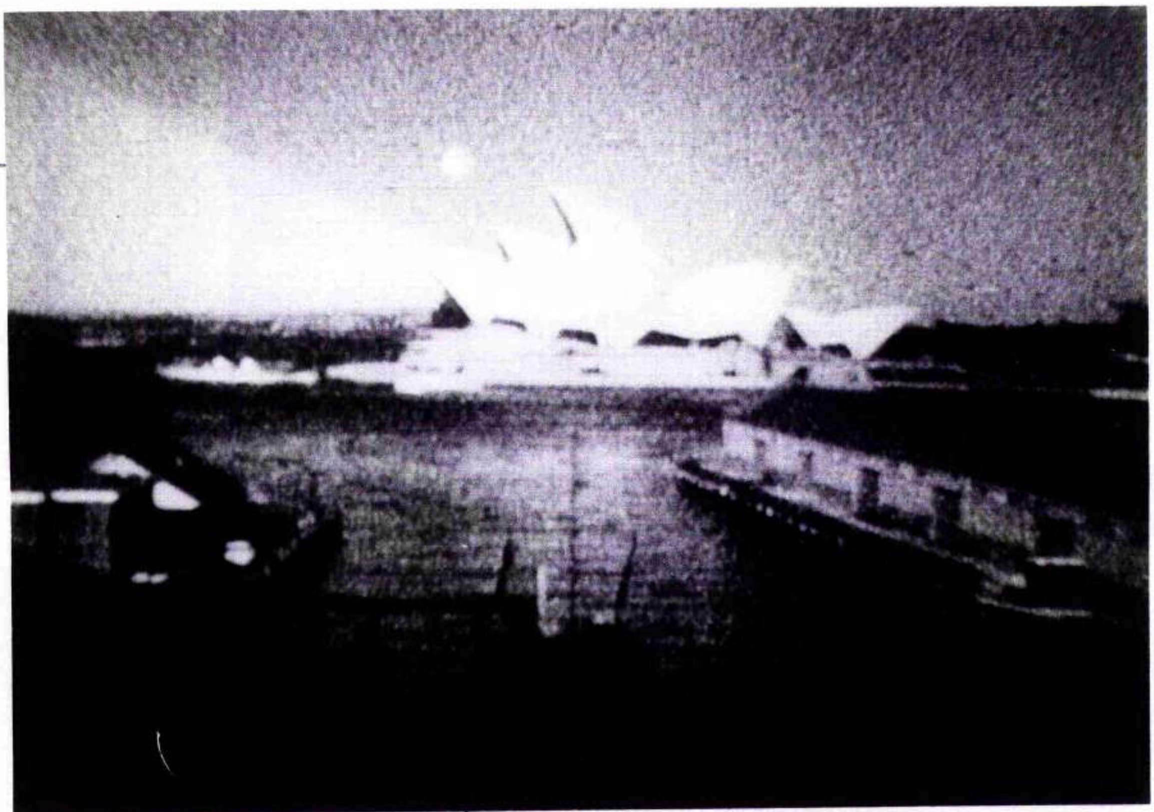
The following pages show examples of photographs used in the vigilance experiment. Position of the signal in the picture is indicated by marking its (x,y) co-ordinates in black on the border of the photograph.

The photographs were taken directly from the television screen to show as closely as possible the actual display seen by the subjects. However, it is extremely difficult to achieve satisfactory clarity and contrast by this method. (For example the variable diagonal 'shadowing' in the photographs is caused by the electron beam scanning the cathode ray tube. This 'shadowing' is not apparent in normal viewing). Consequently, the pictures on the following pages should be regarded only as indicative of what was shown to the subject. For the actual experiment, the video pictures and signals were of far better quality.

Photograph of signal 18 - showing that it is clearly visible, even when the picture quality is severely reduced by the process of photographing the pattern directly from the television screen.







APPENDIX V: COMPUTER SIMULATION PROGRAM

```
0005 LET G3=0
0010 LET G9=0
0020 LET L1=0
0030 PRINT
0040 PRINT
0050 PRINT "NO. OF CYCLES OF PROG. PARAMS =";
0051 INPUT O1
0060 PRINT
0061 IF G3=0 THEN GOTO 0070
0062 LET G3=0
0063 IF S3=1 THEN GOTO 0070
0064 IF S9=1 THEN GOTO 0070
0065 LET G3=1
0066 PRINT "USE SAME TRIALS & POSN'S 1/0 ";
0067 INPUT G9
0070 LET O9=0
0080 FOR O=1 TO O1
0090  PRINT
0100  PRINT
0110  PRINT
0120  PRINT
0130  PRINT "---------"
0140  PRINT
0150  LET L=100
0160  LET K=0
0170  DIM P[L],E[L]
0175  IF G9=1 THEN GOTO 0270
0180  IF O9=1 THEN GOTO 0230
0190  PRINT
0200  PRINT "NO. OF TRIALS= ";
0210  INPUT N
0220  DIM S[N],U[N]
0230  FOR I=1 TO N
0240    LET S[I]=0
0250  NEXT I
0260  GOSUB 1170
0270  IF O9=1 THEN GOTO 0570
0280  PRINT
0290  PRINT "IS K A VARIABLE (1) OR CONST (0) ?";
0300  INPUT A
0310  IF A=<0 THEN GOTO 0530
0320  PRINT
0330  PRINT "KMAX=";
0340  INPUT K9
0350  PRINT
0360  PRINT "KMIN=";
0370  INPUT K1
0380  IF K1>K9 THEN GOTO 0320
0390  IF (K9-K1)>(L/2-1) THEN GOTO 0320
0400  PRINT
0410  PRINT "ATTENTION LAPSE 1/0? ";
0420  INPUT L1
0430  IF L1=0 THEN GOTO 0570
0440  PRINT
0450  PRINT "KMAX(MIN)=";
0460  INPUT K7
0470  IF K7=<K1 THEN GOTO 0440
```

```
0480  PRINT
0490  PRINT "K1IN(MAX)=";
0500  INPUT K3
0510  IF K3=>K9 THEN GOTO 0430
0520  GOTO 0570
0530  PRINT
0540  PRINT "K=";
0550  INPUT K
0560  GOTO 0570
0570  PRINT
0580  LET T1=0
0590  LET T=0
0600  LET O9=1
0610  FOR W=1 TO N
0620    LET W[W]=0
0630  NEXT W
0640  FOR I=1 TO L
0650    LET P[I]=I
0660    LET E[I]=I
0670  NEXT I
0680  LET S1=0
0690  FOR I=1 TO N
0700    IF A=<0 THEN GOTO 0720
0710    GOSUB 1100
0720    GOSUB 1080
0730    LET S=0
0740    LET S1=0
0750    IF S[I]=0 THEN GOTO 0790
0760    LET S1=1
0770    LET P1=S[I]
0780    LET P[P1]=-P[P1]
0790    FOR J=L9 TO (L9+K)
0800      IF P[J]><E[J] THEN LET S=1
0810    NEXT J
0820    IF S=S1 THEN LET T=T+1
0830    IF S=S1 THEN LET W[I]=1
0840    IF S1><1 THEN GOTO 0870
0850    IF S1=S THEN LET T1=T1+1
0860    LET P[P1]=-P[P1]
0870  NEXT I
0880  PRINT
0890  PRINT "NO. OF SIGNALS PRESENTED= ";S7
0900  PRINT
0910  PRINT "NO. OF SIGNALS DETECTED ";T1
0920  PRINT
0930  PRINT "NO. OF TRIALS =        ";N
0940  PRINT
0950  PRINT "NO. OF CORRECT TRIALS= ";T
0960  PRINT
0970  PRINT "TRIAL NO'S WRONG ARE :-"
0980  PRINT
0990  FOR W=1 TO N
1000    IF W[W]=1 THEN GOTO 1020
1010    PRINT W;",";
1020  NEXT W
1030 NEXT O
1040 PRINT
1050 PRINT "-------**"
1060 GOTO 0030
1070 END
1080 LET L9=INT(.5+RND(K)*(L-K))
```

```
1090 RETURN
1100 LET K=INT(.25+K1+RND(K)*(K9-K1))
1110 IF L1=<Ø THEN GOTO 1160
1120 LET V=((2*I-N)/N)↑2
1130 LET K8=K7+V*(K9-K7)
1140 LET K2=K1+V*(K8-K1)
1150 LET K=INT(.25+K2+RND(K)*(K8-K2))
1160 RETURN
1170 PRINT
1180 IF O9=1 THEN GOTO 1240
1190 PRINT "AUTO SIGNL TRIALS 1/Ø ";
1200 INPUT S9
1210 PRINT
1220 PRINT "AUTO SIGNL PSN 1/Ø ?";
1230 INPUT S8
1240 IF S9=1 THEN GOTO 1490
1250 PRINT
1260 IF O9=1 THEN GOTO 1320
1270 PRINT "NO. OF TRIALS WITH SIGNS= ";
1280 INPUT S7
1290 DIM Y[S7],Z[S7]
1300 IF S7>N THEN GOTO 1250
1320 FOR B=1 TO S7
1330  IF O9=1 THEN GOTO 1370
1340  PRINT
1350  PRINT "TRIAL NO=";
1360  INPUT Z[B]
1370  IF S8=1 THEN GOTO 1430
1380  IF O9=1 THEN GOTO 1410
1390  PRINT "  POSN.= ";
1400  INPUT Y[B]
1405  LET G8=1
1410  LET S[Z[B]]=Y[B]
1420  GOTO 1470
1430  LET S5=RND(K)*(L-1)+1
1440  LET S5=INT(S5+.5)
1450  PRINT " POSN SELECTED= ";S5
1460  LET S[Z[B]]=S5
1470 NEXT B
1480 RETURN
1490 PRINT
1500 IF O9=1 THEN GOTO 1540
1510 PRINT "NO. OF TRIALS WITH SIGNLS= ";
1520 INPUT S7
1530 DIM Y[S7],Z[S7]
1540 FOR T=1 TO S7
1550  LET S6=RND(K)*(N-1)+1
1560  LET S6=INT(S6+.5)
1570  IF S[S6]><Ø THEN GOTO 1550
1580  PRINT
1590  PRINT "TRIAL NO SELECTED= ";S6;
1600  IF S8=1 THEN GOTO 1650
1610  IF O9=1 THEN GOTO 1690
1620  PRINT "  POSN= ";
1630  INPUT Y[T]
1640  GOTO 1690
1650  LET S5=RND(K)*(L-1)+1
1660  LET S5=INT(S5+.5)
1670  PRINT " POSN SELECTED= ";S5
1680  LET Y[T]=S5
1690  LET S[S6]=Y[T]
1700 NEXT T
1710 RETURN
```

UNIVERSITY OF ST. ANDREWS
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From
PROFESSOR M. A. JEEVES

PSYCHOI
Tel:

Ph.D. Thesis written by Mr R B lee

This is to declare that in preparing this Thesis Mr Lee has fi
the conditions of the ordinance and regulations which apply.

Profess Jeeves

1 August 1974